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ECONOMIC SCIENCES

ANALYSIS OF THE DEVELOPMENT DYNAMICS AND KEY DETERMINANTS OF SOCIAL AND CULTURAL SERVICE ACTIVITIES IN THE TOURISM SECTOR

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ABSTRACT

Tourism has evolved into one of the most dynamic and multifunctional sectors of the global economy, playing a significant role in economic growth, social interaction, and cultural exchange. This study examines the development dynamics and key determinants of social and cultural service activities within the tourism sector. Emphasis is placed on understanding tourism as an intangible and intersectoral activity shaped by economic, social, institutional, and environmental factors. Drawing on theoretical perspectives, particularly Krippendorf's concept of leisure in industrial and post-industrial societies, the paper highlights the transformation of tourism from a privilege of limited groups into a mass phenomenon closely linked to quality of life, income growth, and changing social values. The analysis underscores the impact of transportation development, rising incomes, middle-class expansion, and evolving tourist preferences on the growth of social and cultural tourism services. The study concludes that the sustainable development of tourism requires a balanced approach that integrates economic efficiency, cultural authenticity, social inclusion, and environmental responsibility, thereby reinforcing tourism's role as a catalyst for long-term socio-economic development.

Keywords: Tourism sector; Social and cultural services; Economic development; Leisure economy; Sustainable tourism; Quality of life; Post-industrial society.

Introduction

Over time, tourism has come to be recognized as an important catalyst of human activity, industry, and economic development. Like other sectors, tourism utilizes economic resources, creates value, and generates a marketable product. However, unlike traditional goods, this product is intangible in nature and is formed through the joint activities of multiple sectors. Tourism influences both specialized and related industries and has become one of the main sources of income for both developed and developing countries.

In earlier periods, people primarily traveled for purposes related to knowledge, religion, and trade. In other words, the motivation for travel was driven by the search for truth, the practice of religious beliefs, or the discovery of new lands and markets. In later periods, trade was at times replaced by warfare. In the modern era, however, people travel for a wide range of reasons, including business, leisure, religious pilgrimage, cultural experience, visiting relatives, education, and health-related purposes.

As transportation modes have diversified and become faster, travel has expanded to more distant destinations. At the same time, the growth of the middle class and rising income levels have provided a strong stimulus to the development of tourism. Modern tourists are more informed, more demanding, and constantly seek new experiences, alternative destinations, and diversified tourism products.

Thus, tourism is a multifaceted field of activity that originated from ancient human mobility but is now built upon enjoyment, learning, economic value creation, and global interaction.

Krippendorf, in his analysis of the fundamental characteristics of industrial society, emphasized the concept of leisure as one of its most significant outcomes. According to him, individuals in industrial society are primarily engaged with three core dimensions: work, living environment, and leisure. These three dimensions are interconnected through four subsystems:

- Value system, where wealth and consumption emerge as primary objectives;
- Economy, characterized by the emergence of large corporations and the concentration of wealth;
- Government, whose policies directly influence individuals' lives;
- Environment and resources, which may be perceived as either limited or unlimited.

According to Krippendorf, people travel in order to cope with the pressures of daily life and work. He further argues that society is entering a period of profound transformation, after which it will no longer be defined as a "work-centered society." Post-industrial society should prioritize quality of life, freedom, participation, independence, and self-realization. Traditional values such as career, salary, and material security gradually lose importance, while individuals rediscover the meaning of time. Krippendorf concludes that tourism serves as a means for achieving a better quality of life and contributes to the creation of a more harmonious society.

Literature Review

Tourism has long been recognized as a significant driver of economic, social, and cultural development. Early foundational work by Butler (1980) introduced the Tourism Area Life Cycle (TALC) model, emphasizing that tourism destinations evolve through identifiable stages and may face decline if growth is unmanaged. This framework highlighted the necessity of sustainable planning in tourism development. Similarly, Krippendorf (1987) critically examined mass tourism and argued that unregulated tourism growth can lead to

environmental degradation and social disruption, thereby undermining long-term welfare.

The theoretical foundations of sustainable tourism were further developed in the 1990s. Bramwell and Lane (1993) conceptualized sustainable tourism as a dynamic and evolving approach aimed at balancing economic benefits with environmental protection and social equity. Sharpley (2000) expanded this discussion by identifying a persistent theoretical divide between tourism-driven economic growth and genuine sustainable development, arguing that economic expansion alone does not guarantee sustainability unless supported by appropriate governance structures.

Governance and policy effectiveness have been central themes in the sustainability literature. Hall (2011) demonstrated that policy failures in sustainable tourism governance often stem from weak institutional learning, fragmented policymaking, and short-term economic priorities. Complementing this view, Hall, Gössling, and Scott (2015) emphasized responsible tourism governance, arguing that sustainability requires coordinated policies integrating environmental management, social inclusion, and economic resilience.

Environmental pressures—particularly climate change—represent one of the most critical challenges facing tourism. Gössling, Scott, and Hall (2018) identified climate change as a structural risk to tourism systems, affecting destination attractiveness, infrastructure, and seasonal demand. Empirical evidence provided by Scott, Hall, and Gössling (2019) further revealed that tourism destinations are increasingly vulnerable to climate-induced shocks, especially in coastal and developing regions. In parallel, Gössling, Peeters, and Scott (2015) highlighted the growing pressure tourism places on water resources, raising concerns over long-term resource security and environmental sustainability.

The COVID-19 pandemic marked a turning point in global tourism dynamics. According to the OECD (2021), the pandemic exposed the sector's structural fragility and overreliance on international mobility. Recovery strategies emphasized resilience, diversification, and sustainability. The WTTC (2023) and World Bank (2023) reports confirmed tourism's substantial contribution to global GDP and employment while warning that recovery remains uneven across regions. These findings are reinforced by UNWTO (2023), which links tourism recovery directly to progress toward the Sustainable Development Goals (SDGs).

Recent literature increasingly focuses on inclusive growth and income distribution. UNDP (2022) argues that tourism can support inclusive economic development only if local communities actively participate in value creation. However, leakage effects—where tourism revenues flow to foreign investors—limit local benefits, a concern echoed in UNWTO and World Bank (2018). These findings underscore the importance of local ownership, fair income distribution, and community-based tourism models.

Technological transformation has emerged as a double-edged sword in tourism development. Buhalis and Amaranggana (2015) introduced the concept of *smart tourism destinations*, emphasizing personalization, efficiency, and data-driven management. While digitalization enhances competitiveness, Deloitte (2024) warns that unequal access to technology may marginalize small and medium-sized enterprises, exacerbating structural inequalities. Additionally, cybersecurity and data governance have become critical concerns in an increasingly digital tourism ecosystem.

Cultural sustainability constitutes another essential dimension of tourism development. UNESCO (2019) stresses that tourism must preserve cultural heritage rather than commodify it, warning against the loss of authenticity due to commercialization. This aligns with the broader sustainability discourse, which emphasizes that tourism should strengthen cultural identity and social cohesion rather than erode them.

At the global policy level, the World Economic Forum (WEF, 2025) provides a forward-looking perspective, arguing that tourism is transitioning toward a human-centered, sustainable, and inclusive growth model. The report emphasizes climate neutrality, digital equity, and resilience as the core pillars of future tourism development. This vision aligns with earlier academic contributions but also reflects emerging global challenges such as geopolitical instability, environmental stress, and technological disruption.

A growing body of empirical literature has examined the structural determinants of economic development in Azerbaijan, with particular emphasis on trade integration, investment flows, financial development, and sectoral dynamics. Early contributions focus on Azerbaijan's integration into the global economy and its implications for macroeconomic performance. **Guliyev and Huseynova (2016)** analyze the relationship between imports and annual GDP using econometric models within the context of Azerbaijan's prospective accession to the World Trade Organization (WTO). Their findings indicate a strong long-run relationship between import dynamics and economic growth, non oil sectors and suggesting that trade liberalization can stimulate domestic production through access to intermediate goods and technology transfer.

Closely related to trade integration, **Huseynova (2014)** discusses the structural and institutional challenges Azerbaijan faces in joining the WTO. The study highlights issues such as tariff harmonization, competitiveness constraints, and institutional readiness, arguing that WTO accession could enhance economic efficiency but requires substantial regulatory reforms. Expanding on international linkages, **Huseynova (2016)** investigates the impact of international migration on trade flows, demonstrating that migration networks facilitate bilateral trade by reducing transaction costs and improving information flows. This finding underscores the broader role of globalization in shaping Azerbaijan's trade performance.

Exchange rate dynamics and external balance have also received considerable attention. **Alirzayev and Huseynova (2025)** provide empirical evidence on the J-curve effect and the Marshall–Lerner condition for Azerbaijan. Using time-series econometric techniques, they show that currency depreciation initially

worsens the trade balance but leads to long-term improvement, confirming classical international trade theory within the Azerbaijani context. These results emphasize the importance of exchange rate policy for sustainable external adjustment of non oil sectorss.

Investment and capital formation represent another central theme in the literature. **Huseynova and Kazimov (2025)** examine investment incentives as a policy tool for sustainable economic development in Azerbaijan. Their analysis suggests that targeted fiscal and institutional incentives positively affect investment inflows and long-term growth, particularly when aligned with strategic non oil sectors. Similarly, **Charkasov and Huseynova (2024)** analyze the determinants of foreign direct investment (FDI) inflows using the ARDL bounds testing approach. The study finds that macroeconomic stability, market size, and institutional quality play a significant role in attracting FDI, reinforcing the view that stable policy frameworks are crucial for sustainable development.

The financial sector has also emerged as a key driver of economic modernization. **Huseynova and Balajayeva (2025)** investigate digital banking regulation in Azerbaijan, focusing on user trust, risk management, and data protection. Their empirical findings indicate that effective regulatory frameworks enhance trust in digital financial services, which in turn supports financial inclusion and economic resilience. This study contributes to the broader literature linking financial innovation with sustainable economic growth.

Sector-specific analyses further enrich the understanding of Azerbaijan's development trajectory. **Huseynova and Rzayeva (2025)** empirically examine the relationship between the tourism sector and economic growth in Azerbaijan. Their results reveal a positive and statistically significant relationship, suggesting that tourism can serve as a complementary engine of growth alongside the energy sector. This finding is particularly relevant in the context of economic diversification and post-pandemic recovery strategies.

Taken together, these studies highlight that Azerbaijan's sustainable economic development is influenced by a complex interaction of trade integration, investment dynamics, financial sector modernization, and sectoral diversification. While earlier research emphasizes external trade and institutional reforms, more recent contributions increasingly focus on innovation, digitalization, and service-sector development. The literature collectively suggests that long-term growth in Azerbaijan depends not only on natural resource revenues but also on effective macroeconomic policies, institutional quality, and diversification strategies supported by empirical evidence.

In summary, the existing literature demonstrates that tourism can significantly contribute to economic growth and development; however, its long-term sustainability depends on effective governance, environmental responsibility, social inclusion, and technological balance. Contemporary research increasingly converges on the view that sustainable tourism is not merely an economic strategy but a multidimensional development paradigm requiring integrated policy frameworks and global cooperation.

Methodology

The main objective of this study is to analyze, on a dynamic basis, the impact of the tourism sector and related socio-cultural services on the development of the Azerbaijani economy. In particular, the research focuses on identifying long-term and short-term relationships between tourism activity indicators and macroeconomic variables. To achieve this objective, dynamic analytical methods are employed.

Analyses and Discussion .To understand tourism comprehensively, it is essential to consider the perspectives of five key stakeholder groups involved in this sector:

- Tourists: Their motivation to travel depends on time availability, financial capacity, and social and cultural characteristics. These factors determine the choice of tourism destinations and activities.
- Business sector: This includes companies that offer products and services to meet tourists' needs. The tourism industry is divided into transportation, accommodation, shopping, and entertainment services.
- Governments of tourist-generating countries: These governments view tourism as a source of foreign currency inflows and an important economic and political instrument. In some countries, particularly those with socialist systems, regulating this flow is vital for economic stability.
- Governments of host countries: They benefit from tourism through income generation, employment creation, and tax revenues.
- Host communities: The effects of tourism are most strongly felt at this level. While tourists bring income, employment opportunities, and cultural exchange, they may also generate environmental and social challenges.

The interaction among these five groups increases the complexity of tourism while simultaneously contributing to greater global understanding and interconnectedness.

From a scientific perspective, tourism consists of four main elements:

Dynamic element – The tourism phenomenon

Tourism was once accessible only to privileged groups, but over time it has evolved into a mass cultural lifestyle. This phenomenon is characterized by continuous change and possesses significant potential for personal, social, and physical development.

Service element – The tourism system

The tourism system is an open and interconnected structure comprising two main components:

- Demand side: tourists' behavior and characteristics;
- Supply side: destination resources and services.

The connecting elements between demand and supply include advertising, transportation, tour operators, sales channels, and pricing strategies.

Functional element – Tourism management

Tourism management refers to the execution of necessary functions to achieve predefined objectives. This process requires coordination among tourists, local communities, companies, non-governmental organizations, and government institutions.

The objective of the tourism system is to ensure an optimal balance between benefits and costs arising from the integration of all components. A fundamental principle in this process is the preservation of cultural authenticity and hospitality. Hospitality refers to the practice of offering kindness, care, safety, and comfort to guests.

Through tourism, the exchange of cultural and human experiences should meet the needs of both tourists and host communities. When all stakeholders adhere to the principle of "think globally, act locally," tourism can achieve its ideal outcome—mutual respect, cultural understanding, and sustainable development.

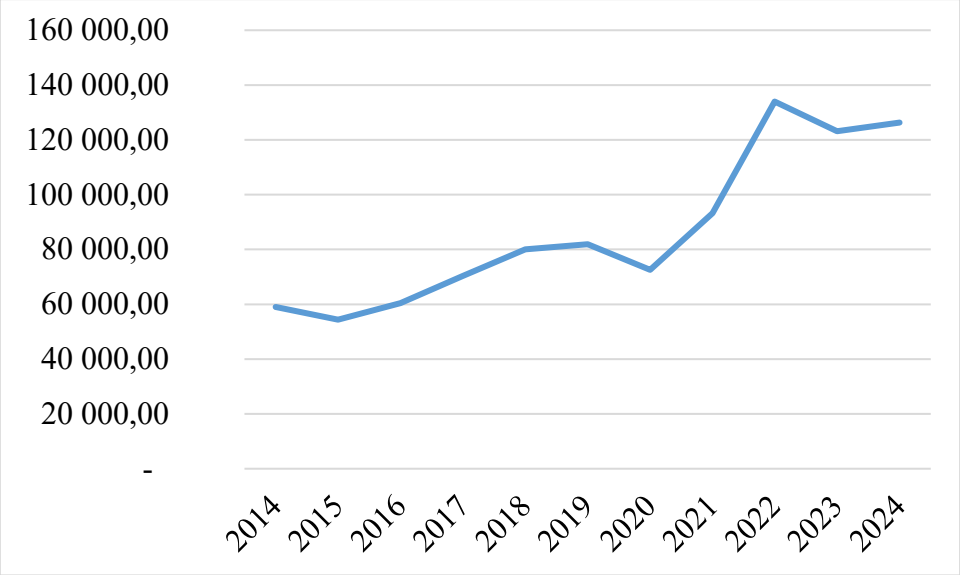

Figure 1. Gross Domestic Product (GDP), million AZN

Source: Prepared by the author based on data obtained from the State Statistical Committee.

Figure 2 illustrates the changes in Gross Domestic Product (GDP) (million AZN) over the period 2014–2024 and highlights both phases of steady growth and periods of pronounced fluctuations characterized by sharp jumps. In 2014, GDP amounted to approximately 58 billion AZN; however, during 2015–2016 it experienced a contraction, declining to around 55 billion AZN. This downturn can largely be attributed to the fall in global oil prices and prevailing macroeconomic instability.

From 2017 onward, a recovery in economic activity is observed, with GDP increasing steadily and reaching a relatively stable peak of about 78 billion AZN in 2019. In 2020, however, GDP weakened again, falling to nearly 70 billion AZN as a result of the COVID-19 pandemic. Since 2021, the economy has entered a recovery phase, with a particularly sharp increase in 2022, when GDP rose to over 135 billion AZN. This surge can be associated with higher oil revenues in the post-pandemic period, the revival of economic activity, and increased public investment projects.

Although a slight decline is observed in 2023, GDP appears to have returned to an upward trajectory in 2024, moving toward stabilization at approximately 125 billion AZN. Overall, the figure indicates the presence of a long-term growth trend, while also demonstrating the economy's high sensitivity to oil price fluctuations and global economic shocks.

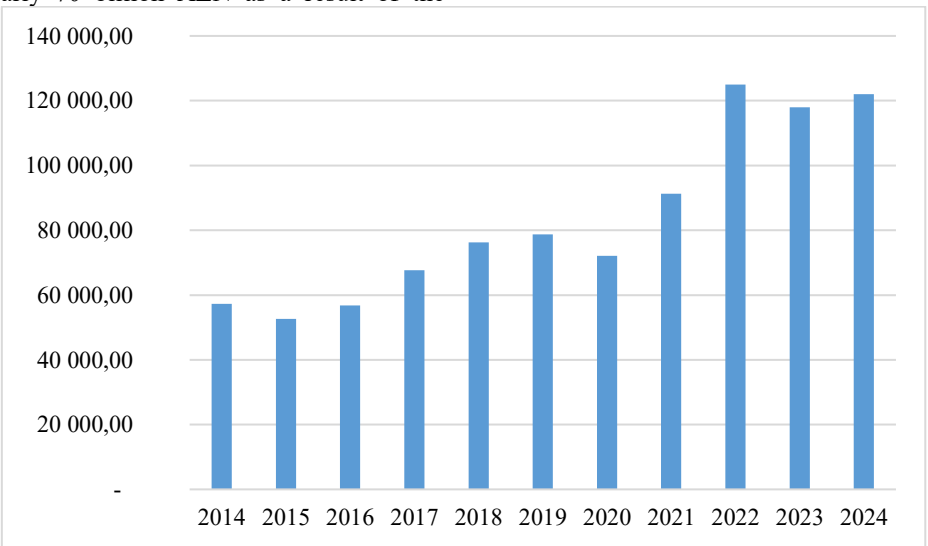

Figure 2. Gross National Income (million AZN)

Source: Prepared by the author based on data obtained from the State Statistical Committee.

The figure illustrates the changes in Azerbaijan's **national income** (million AZN) over the period 2014–2024 and clearly shows both phases of decline and periods of sustained growth throughout the sample. In 2014, national income amounted to approximately 57 billion AZN; however, in 2015 it declined to around 52 billion AZN, reflecting the impact of economic instability. In 2016, the indicator recovered slightly, returning to nearly 57 billion AZN.

From 2017 onward, a phase of steady growth in national income is observed. The indicator exceeded 70 billion AZN in 2018 and reached about 78 billion AZN in 2019. This period is characterized by the recovery of economic activity, stabilization of the investment environment, and renewed strengthening of the energy sector. In 2020, however, national income declined to around 72 billion AZN due to the adverse effects of the COVID-19 pandemic.

Beginning in 2021, a strong upward trend in national income emerges. The indicator rose to approximately 92 billion AZN in 2021 and recorded a sharp increase in 2022, surpassing 125 billion AZN. This growth can be attributed to post-pandemic economic recovery, rising global energy prices, and increased revenues from oil and gas exports. Although national income decreased somewhat in 2023 to about 118 billion AZN, growth resumed in 2024, with the indicator stabilizing at around 122 billion AZN.

Overall, the figure suggests that national income follows a long-term upward trend, while remaining highly sensitive to global price fluctuations and external economic shocks.

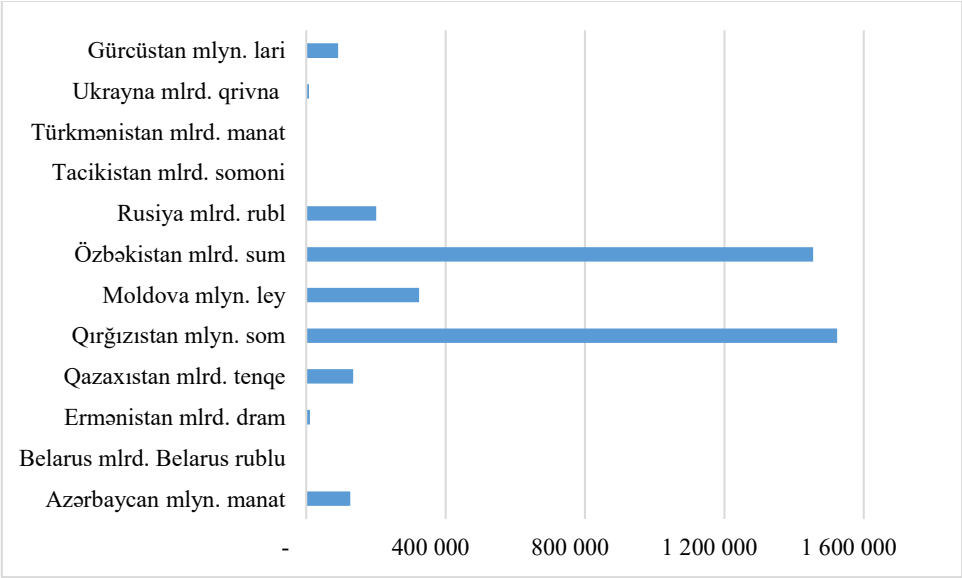

Figure 3. Gross Domestic Product (national currency units)
Source: Prepared by the author based on data obtained from the State Statistical Committee.

The figure presents a comparative overview of **GDP indicators measured in national currencies** for various post-Soviet and regional countries, clearly highlighting differences in economic size, currency denomination, and sharp disparities in nominal values. It is observed that **Uzbekistan** records the highest nominal GDP, reaching approximately **1,350,000 billion soums**. This figure reflects not only the high denomination of the Uzbek currency but also the country's relatively broad economic base.

Kyrgyzstan's GDP measured in national currency appears even larger in nominal terms, approaching **1,600,000 billion soms**. This outcome primarily reflects the very low value of the national currency, which inflates nominal figures and illustrates the country's underlying monetary structure rather than real economic scale. **Moldova**, with a GDP of approximately **280,000 million lei**, is positioned among mid-sized economies in nominal terms.

Russia's GDP expressed in national currency appears comparatively more moderate, amounting to around **150,000 billion rubles**. Considering the denomination characteristics of the ruble, this represents a structurally consistent nominal magnitude. **Kazakhstan's** GDP stands at approximately **90,000 billion tenge**, reflecting the nominal scale of an economy largely driven by energy resources.

Among the **South Caucasus countries**, Azerbaijan and Georgia exhibit relatively lower nominal GDP figures. Azerbaijan's GDP is approximately **120,000 million manats**, while Georgia's GDP amounts to about **65,000 million .Belarus** display comparatively smaller nominal values, indicating more compact economic structures.

Overall, the figure demonstrates that nominal GDP indicators are highly dependent on the value and denomination of national currencies. Therefore, meaningful cross-country economic comparisons require the use of additional measures, such as **exchange rate adjustments** and **purchasing power parity (PPP)**–based indicators.

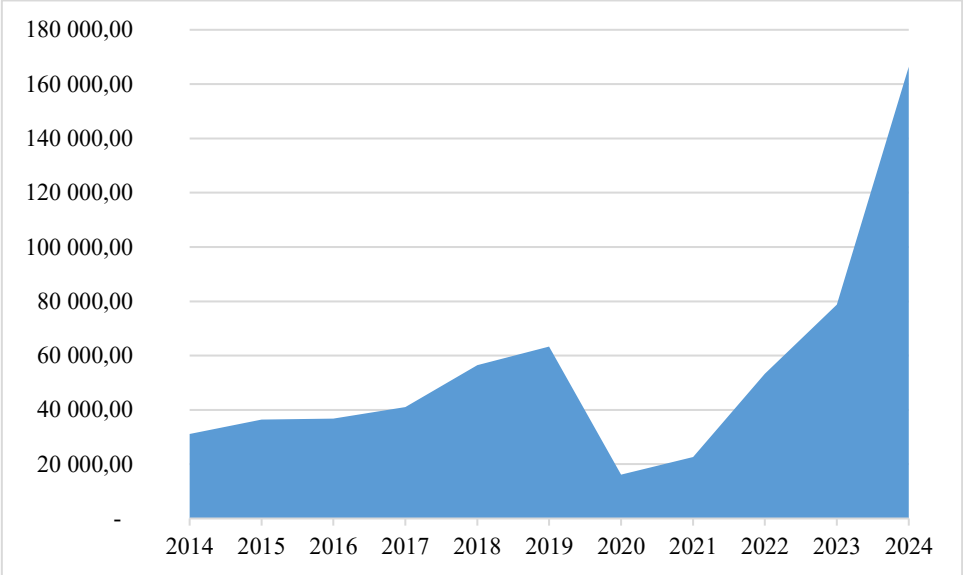

Figure 4. Revenue earned by travel agencies and tour operators (thousand manats)
Source: Prepared by the author based on data obtained from the State Statistical Committee.

The figure illustrates the changes in revenues earned by travel agencies and tour operators (in thousand manats) over the period **2014–2024**, clearly demonstrating the tourism sector's high sensitivity to macroeconomic shocks. In 2014, revenues amounted to approximately **32 thousand manats**, increasing to **38 thousand manats** in 2015, which indicates an expansionary trend in the sector. During **2016–2017**, revenues remained relatively stable, with only marginal growth observed.

In **2018**, increased activity in the tourism sector led revenues to exceed **55 thousand manats**, and in **2019**, the sector reached its first peak of approximately **65 thousand manats**. However, in **2020**, due to the impact of the global **COVID-19 pandemic**, revenues declined sharply to around **15 thousand manats**, representing the lowest level over the entire period and clearly evidencing the severe shock experienced by the tourism industry.

In **2021**, initial signs of recovery emerged, with revenues rising to about **22 thousand manats**. From **2022 onward**, the sector entered a positive trajectory, with revenues increasing rapidly to **45 thousand manats** in 2022 and **80 thousand manats** in 2023. In **2024**, a dramatic surge occurred, with revenues reaching **165 thousand manats**, the highest value recorded during the period under review. This substantial increase can be attributed to the post-pandemic recovery of tourism flows as well as growing demand for both domestic and international tourism products.

Overall, the figure indicates that although the tourism sector is highly exposed to severe shocks, it also exhibits strong recovery potential, achieving a historical maximum in 2024 and entering a phase of dynamic growth.

Tourism is one of the most dynamic and multifaceted sectors of the twenty-first century. It is regarded not only as a driver of economic development but also as a key instrument of cultural integration and global understanding. However, in the post-pandemic era and under conditions of intensified globalization, the tourism sector has faced profound structural and functional challenges.

According to the **World Economic Forum (WEF)** report *"Future of Travel and Tourism 2025"*, tourism is no longer merely associated with travel and leisure but is increasingly transforming into an ecosystem rebuilt around the principles of sustainability, technology, and social equity. Nevertheless, this transformation has revealed numerous global challenges, including environmental degradation, unequal income distribution, geopolitical instability, infrastructure fragility, and technological inequality, all of which pose serious threats to the future of tourism.

1. Environmental and Climate-Related Challenges

The WEF report indicates that tourism accounts for approximately **8–10 percent of global greenhouse gas emissions**, with the growing share of air transportation significantly increasing the carbon footprint. In mass tourism destinations—such as Venice, the Balearic Islands, Banff, and Machu Picchu—*overtourism* leads to the depletion of natural resources, disruption of local ecosystems, and loss of biodiversity.

As a result, the concept of the **Green Transition** has become a core priority for the tourism sector. The WEF emphasizes that future tourism enterprises must adopt carbon neutrality, waste reduction, and circular resource-use principles. However, in many developing countries, this transition is hindered by economic constraints and technological limitations.

2. Long-Term Socioeconomic Impacts of the Pandemic

The COVID-19 pandemic nearly halted global tourism. While global tourism revenues amounted to approximately **USD 9 trillion** in 2019, they declined to about **USD 2 trillion** in 2020. The post-pandemic recovery has been uneven: Europe and North America rebounded relatively quickly, whereas regions such as Asia, Africa, and Latin America have struggled to return to pre-pandemic levels.

Moreover, the pandemic exposed the vulnerability of tourism workers. The WEF report notes that more than **50 percent** of global tourism employment is informal, placing workers at high risk in terms of income security and social protection.

3. Economic Inequality and Income Distribution

Tourism is often portrayed as a "development engine," yet WEF analyses reveal that income distribution is frequently asymmetric. Large tourism corporations and international brands capture the majority of revenues, while local communities receive only a small share.

In developing countries, more than **70 percent** of tourism revenues often flow to foreign-owned hotels and airlines—a phenomenon known as the **leakage effect**, whereby income does not fully circulate within the local economy. Consequently, despite nominal growth, tourism may have a limited impact on local welfare. These inequalities can also fuel social tensions, with tourism increasingly perceived by local populations as a form of "social intrusion" in certain regions.

4. Technological Transformation and Digital Dependence

Digital technologies play a crucial role in the recovery of tourism. Artificial intelligence, big data, cloud technologies, and smart destination models enhance service quality and management efficiency. However, the WEF highlights that access to these technologies is uneven.

Digitalization tends to disadvantage small and medium-sized enterprises, which struggle to compete with technologically advanced large corporations. At the same time, concerns related to data privacy and cybersecurity are increasing. The report notes that cyberattacks targeting tourism companies increased by **30 percent in 2024**. Furthermore, excessive automation may undermine the human and emotional value traditionally associated with hospitality services.

5. Geopolitical and Security Risks

Tourism is directly dependent on international peace and stability. Recent geopolitical developments—including the war in Ukraine, tensions in the Middle East, and terrorist incidents—have significantly disrupted tourism flows. According to the WEF, tourist arrivals to the Middle East declined by **40 percent** during 2023–2024 due to geopolitical instability.

In addition, migration crises and changes in visa regimes negatively affect tourism. Increasing global security measures—such as stricter border controls, biometric identification, and sanctions—raise travel costs and constrain mobility.

6. Social and Cultural Identity Challenges

Tourism is not only an economic activity but also a platform for cultural interaction. However, globalization has increasingly led to cultural homogenization. The dominance of international brands often diminishes the authenticity of local cultural experiences.

In some destinations, culture is artificially constructed and commodified, particularly in ethnic and rural tourism. The WEF describes this process as **cultural commodification**, warning that excessive commercialization of cultural values may result in long-term identity crises within societies.

7. Infrastructure and Sustainability Constraints

In many tourism destinations, infrastructure—transport, energy, waste management, and water supply—is unable to accommodate tourism flows. This problem is especially pronounced in developing countries, where renewable energy and environmentally friendly infrastructure remain insufficient.

The WEF 2025 report notes that in more than **30 tourism regions worldwide**, including the Maldives, the Philippines, and Tanzania, excessive tourism-related water use has restricted local populations' access to potable water.

8. Human Resources and Skills Mismatch

Approximately **80 percent** of tourism employment is concentrated in the service sector, yet skill gaps are rapidly widening. Deficiencies in digital skills, language proficiency, and customer-oriented training negatively affect service quality.

More critically, tourism jobs are often low-paid and unstable, reducing worker motivation and contributing to talent outflows. The WEF 2025 report emphasizes that sustainable tourism development is impossible without sustained investment in human capital.

9. Sustainable Tourism and Inclusiveness

The future of tourism must be built upon the principles of **sustainability** and **inclusiveness**, encompassing not only environmental protection but also economic and social justice.

According to the WEF **Travel & Tourism Development Index**, by 2025, around **40 countries** have begun aligning tourism development strategies with the **UN Sustainable Development Goals (SDGs)**. In particular, the **Responsible Tourism** model—emphasizing local community participation in decision-making and fair income distribution—has emerged as a key direction.

10. Outlook for the Future of Tourism: A Reconfigured Global Ecosystem

Looking beyond 2025, the WEF predicts that tourism will transition toward a **human-centered, technologically integrated, and environmentally neutral** model. Future tourism systems are expected to feature:

- Smart tourism cities managed through real-time data ecosystems;
- Zero-emission strategies, including green aviation and renewable-energy-based facilities;
- Local innovation hubs built on community knowledge and creativity;
- Digital equity, ensuring equal access to tourism technologies and data security.

In conclusion, tourism plays a vital role in global social, economic, and cultural life. However, rapid growth, technological inequality, and environmental pressures have disrupted its balance. The WEF 2025 report underscores that the primary objective of tourism development should not be merely revenue generation, but the preservation of human well-being and planetary health.

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PHILOLOGICAL SCIENCES

THE FIRST TURKOLOGICAL CONGRESS AND THE PRINCIPLE OF ECONOMY IN THE LANGUAGE SYSTEM

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ABSTRACT

Regardless of their agglutinative or inflectional nature, all languages of the world possess the capacity to manifest the principle of linguistic economy in one form or another. At the First Turkological Congress convened in Baku on February 26, 1926, a wide range of issues—such as the alphabet, spelling and orthography, terminology, methods of language teaching, the interaction of related and neighboring languages, the literary language of Turkic languages, the theory of a proto-language, and the history of Turkic languages—were discussed and interpreted. Within the framework of these discussions, attention was also paid to the system of linguistic economy, and several of its characteristic features were briefly analyzed. This article aims to present an analytical perspective on that issue and to highlight how the principle of economy was implicitly addressed within the linguistic debates of the Congress.

Keywords: principle of economy; levels of the manifestation of economy; physiopsychological economy; reflection of this problem in Shcherba's report.

At the First Turkological Congress, Lev Vladimirovich Shcherba, who individually represented Russia, addressed the issue of economy in his report entitled "The Basic Principles of Orthography and Their Social Significance." While discussing the four fundamental principles of orthography—phonetic, etymological, historical, and ideographic—he expressed certain views related to the economy of time, which undoubtedly referred to the ease and efficiency of reading a given material (11, p. 53).

In addressing linguistic economy, Professor Shcherba was the first in world linguistics to articulate a logical and convincing idea about achieving the expression of substantial meanings with minimal expenditure of energy. Naturally, the author's views—originally explained on the basis of the norms and rules of Russian orthography and orthoepy—are also fully applicable when extended to the phonetic laws of more than twenty-five Turkic languages. From this perspective, his views on orthography and orthoepy—particularly those concerning economy in the reading process—were unanimously welcomed with applause by the participants of the Congress. One of those who expressed clear support was Professor Lev Ivanovich Zhirkov of the Russian Association of Eastern Peoples. This Moscow-based scholar participated in the meeting as a co-rapporteur on orthographic issues and devoted considerable attention in his presentation to Shcherba's arguments. By substantiating Shcherba's ideas, he further elaborated on the issue of economy of time and articulated the following points in this regard. "I would like to substantiate what Professor Shcherba said about the importance of orthography as a social institution. He quite rightly points out that when we read a newspaper, we immediately perceive words with our eyes, which results in saving time, and this economy occurs on a nationwide scale for everyone. If you pick up a newspaper and there is a mistake in it, you begin to waste time, because you start thinking: why is it written this way, perhaps it is a printing error, perhaps it indicates something, perhaps it is simply a mistake—and in doing so you lose time. If, as enterprises concerned with the scientific organization of labor do, one were to calculate all the time losses caused by the imperfection of orthography, the result would be an enormous amount of time lost by a nation due to deficiencies in orthography and the fact that many people do not know it properly. I encounter this issue very often; it is a particularly sensitive matter for me. In Moscow, I have students who study Persian, and when they translate from Persian into Russian, I require them to write using correct Russian orthography."

"They object, they do not want to do it, but I tell them that refusing to write the way everyone else writes means committing a crime and stealing the nation's time. Therefore, for the Turks—whose orthography has been developed less than that of many other peoples—I consider orthographic issues to be among the central matters of this Congress. In my opinion, your decision will have a serious impact on the future fate of Turkic orthography" (2, 157–158). From the quotation we have presented extensively from his speech, it becomes clear that he attached greater importance to the linguo-social dimension of linguistic economy, or to the strong semantic relationship between language and culture. In this sense, the linguocultural aspects of the principle of economy found their first embryonic reflection here in world linguistics. Both Shcherba and Zhirkov, in their reports, focused primarily on the orthographic and orthoepic aspects of the principle of economy, substantiating their views by providing rich examples related to the differences between pronunciation and spelling.

It is well known that, historically, terminological lexical units related to various fields of science, economy, and agriculture entered the Turkic languages rapidly from Arabic and Persian, as well as from European languages. While the incorporation of religious and other related terms into Turkic languages dates back to

the 8th century, the influx of European lexical items corresponds mainly to the mid-19th and early 20th centuries. Borrowings from Russian, however, became much more extensive beginning in the first decades of the 20th century.

Extensive information on this issue is presented in the report entitled “On the Principles of the Formation of Scientific Terminology in the Turkic Languages” by the Estonian literary scholar Simunyagi Artur Rudolfovich Ziffeld. In his presentation, the speaker emphasized that even after making use of all dialects and vernaculars of the folk language, certain gaps would still remain in the literary languages with regard to terminology. To fill these gaps, he outlined the necessity of adhering to several principles, presented in four key points, one of which directly concerned the psychophysiological aspect of linguistic economy. These factors were reflected in his speech as follows:

1. The borrowed word must not exceed the phonetic limits characteristic of the recipient language (for example, it should not contain the “ü” affricate); 2) the borrowed word may only include sound correspondences and phonetic features inherent to the recipient language (for example, the word should not begin with a consonant diphthong); 3) the borrowed word must comply with the language’s harmony rules; 4) in terms of the speaker’s psychophysical economy, it is essential to strictly maintain the general stylistic norm of the language (3, p.177). As seen from the fourth point, the speaker emphasized that the psychophysiological aspect of linguistic economy is closely linked with the stylistic characteristics of any given language. In the world, due to the development and complexity of science, economics, technology, agriculture, political life, and similar fields, a significant number of specialized and abbreviated terms have emerged in various languages. In his report, Ziffeld touches upon these terms and evaluates them as units of time-saving, stating that:

“Our Azerbaijani intellectuals are debating: should abbreviated words such as ‘komandarm,’ ‘ispolkom,’ ‘NEP,’ ‘VES,’ etc., be incorporated? We are fully convinced that not only can they be, but they must, because abbreviated words convey maximum meaning in minimal time. Abbreviated words began to emerge in Germany even before the war, during the period of intense capitalist development. As you may recall, in Russia, abbreviated words started appearing during the world war period. In military technology, conciseness and time-saving are essential. ‘Glavkoverkh,’ ‘komandarm’—these are not Soviet words; they predate the Soviet era. The Soviet regime generated mostly new words. The Turkic languages will inevitably follow this example” (3, 178). After the October Revolution, the incorporation of abbreviated words—lexical units formed by retaining only the initial letters or first syllables and omitting the remaining parts—into Turkic languages, including Azerbaijani Turkish, accelerated even further. In the field of terminology, A. Zeynally, in his joint report “On the Scientific Terminology System for Turkic Languages,” briefly described such abbreviations as a form of formal economy (4, 187). Therefore, the content discussed at the Congress regarding linguistic economy largely corresponds to these practices. However, some participants from Turkic nations also expressed additional opinions on linguistic economy, which were not recorded in the stenographic materials. For example, the contributions of Azerbaijani Turkish representative Abdulla Tagiyev, a student at the Leningrad Institute of Oriental Languages and Literature, and the Uzbek representative, teacher Khalid Said Khojayev, who was individually invited from Baku, were not recorded in the stenographic materials. However, these authors further developed, generalized, and refined their presentations in the years following the Congress, culminating in the joint publication of their book Müxtəsər Üslubiyyat in Baku in 1933. In this work, they provided a detailed explanation of the aspects of linguistic economy, including elements such as questions, points, permissions, abbreviations, and substitutions. In the work, the following explanation is given regarding the question indicator: “Sometimes the subject, sometimes the predicate, and sometimes one or several secondary elements of the sentence are omitted, and occasionally all sentence elements are omitted, with the idea expressed by these omitted elements conveyed through a single separate word. For example, when someone asks ‘Has the teacher arrived?’ we respond with ‘Arrived.’ Here, the word ‘Arrived’ represents a sentence in which the subject has been omitted” (5, p. 39).

In the point factor, purpose and intonation are taken as the basis. For instance, the title of the collection may be Revolution and Culture or expressed as It is Revolution and Culture. High-intonation abbreviations are also included, such as Fire! Airplane! Telephone! (meaning “There is a fire,” “The airplane is flying,” “The telephone is ringing”) (5, p. 41).

The permission factor refers to shared words included in various symptomatic parts: In the permission factor, an example is: “You gave the money, and I spent it” (5, p. 41).

In the ellipsis factor, the omission of parallel elements in consecutive sentences is considered. For instance: “I have read all of Lenin’s works. You have read all of Lenin’s works” becomes simply “I have read all of Lenin’s works. You have read” (5, p. 41), and so on.

In the substitution factor, the focus is on the substantivization of adjectives, i.e., their ability to replace nouns. For example: “Those who worked passed the exam well, while those who didn’t were expelled from school.” Here, although those who worked and those who didn’t serve as subjects, logically the main subjects are the nouns they define. These sentences can be completed as: “The students who worked passed the exam well, while the students who didn’t were expelled from school” (5, p. 41).

Over the 100 years since the Congress, there was a stagnation in research on linguistic economy in the Turkological field between 1940 and 1960. Starting from the 1960s, separate publications and monographs on this topic began to appear among Russian, European, and Turkic scholars. In both foreign and local literature, approaches to the principle of linguistic economy have been multi-faceted, and to this day, stylistic, grammatical, and psycholinguistic types of economy each encompass specific subtypes of economization. In

our view, it would be more accurate to include phonological-morphological, lexical-semantic, and syntactic indicators under the stylistic type of economy, while the psycholinguistic types should encompass linguocognitive, explicit, and implicit speech elements. For example, one of our Azerbaijani scholars who approached the principle of economy from a stylistic perspective, Ə. Dəmirçizadə, in his fundamental work Azərbaycanca Dilin Üslubiyyatı published in 1962, preferred using terms such as "abbreviation," "shortening," and "laconicization" more actively instead of the phrase "principle of economy," which, in essence, condition the concept of economy itself. Ə. Dəmirçizadə considers certain violations of the general language norm to be acceptable, characterizing them as forms of linguistic concessions. The researcher discusses the variety of such concessions and notes that some, as a result, create entirely new categories. For instance, in possessive constructions, the omission of the possessive case has ultimately led to the formation of a specific grammatical rule—expressions such as şəhərin qapısı ("city's gate") or dağın başı ("mountain top") evolved alongside forms like şəhər qapısı and dağ başı, which became standardized. Therefore, we consider such cases not as exceptions to a rule but as established norms within modern Azerbaijani. The analysis throughout the work demonstrates that the researcher emphasizes the phonological-morphological type of stylistic economy, offering scientifically and logically valuable propositions.

The term "linguistic economy" was first used in Azerbaijani philology by Z. Budaqova. In 1970, in her collection of articles Stylistics of the Azerbaijani Literary Language, published by Elm Publishing House, she thoroughly examined the section on "types of sentences according to purpose and intonation." In the subsection on imperative sentences, she extensively employed the expression "used economically" to demonstrate that "elliptical imperative sentences are widely used in literary works." The omission of certain words in these sentences further enhances the expressiveness of the idea, making it figurative and economical while emphasizing the main purpose. Some of these sentences carry the character of a request or command (7, p. 281). The thematic content of the author's study indicates that she favored the linguo-syntactic type of economy, generalizing her observations according to this type of economy.

Among the components of syntactic repetitions, the fonomorphological and linguo-syntactic types of the economy principle are most prominently manifested. Extensive scientific and theoretical insights on this topic can be found in M. Adilov's monograph Syntactic Repetitions in the Azerbaijani Language. Similar to Ə. Dəmirçizadə, Adilov preferred to use terms such as "shortening," "specialization," and "condensation" instead of the explicit expression "economy" (8; 18, pp. 26–32).

In Azerbaijani linguistics, there are research studies on the principle of economy in which the fonomorphological, formal, structural, and psycholinguistic types of linguistic economy are integrated, and the research directions are carried out from these perspectives. For example, the most comprehensive study on linguistic economy in Azerbaijani was first conducted by H. Yusifov. In 1976, he defended his candidate dissertation on the topic Economy in the Language System (Based on Azerbaijani Language Materials), in which he analyzed crucial aspects of economy through a rigorous evaluative framework. According to the scholar, it "is a regular linguistic phenomenon in the language and determines the emergence of certain norms" (9, p. 4). The researcher considered the communicative function of language as the main criterion for economy in the language system, evaluating elements that deviate from this function as economical forms, and extensively discussed the importance of using this criterion in determining various language norms (9, p. 4). In this study, which is divided into three chapters, the scholar analyzed the principle of economy at the levels of phonemes, morphemes, and sentences, and supported his theoretical claims with abundant examples drawn from literary works and spoken language.

In 2008, the Linguistics Encyclopedia published by Mütərcim Publishing highlighted the psycho-physiological type of the economy principle, stating that "the law of economy [expenditure of minimal effort], characterized as one of the factors influencing language changes, essentially enables the speaker to express their thought with minimal energy. The law of economy manifests at all levels [layers] of language. Based on the principle of expending minimal effort, the law of economy results in the reduction or omission of sounds, sound combinations, and syllables in various positions of words in Azerbaijani, for example: [sora → sonra, savayı → savay], [Tarverdi → Tanrıverdi], [tabelik → tabelilik], etc. "At the level of word formation, various abbreviations, contractions, and compound words formed from word combinations are also considered units and phenomena related to the principle of economy" (10, p. 425). From the general content and meaning of this brief overview, it is evident that the statements made here fully correspond to, and align with, what Shcherba and Ziffeldin discussed regarding psychophysiological economy at the Turkological Congress.

"Examples in poetry demonstrate economy at the phonemic, morphemic, lexemic, semiotic, and syntactic levels, and in each line, stanza, and complete text, one encounters language rich in economy. On this subject, M. Huseynov, in his monograph Dil və Poeziya (Language and Poetry), provides brief commentary, noting—based on the stylistic type of economy—that 'the conciseness of meaning volume is such an indivisible unity in which all shades of a word and its semantic-stylistic potential are utilized to the maximum in poetic activity'" (11, p. 70).

"The researcher K. Həbibova, in her article A Psycholinguistic Interpretation of the Economy Principle in the Language of the 'Kitabi Dədə-Qorqud' Epics published in Türkologiya, 2011, Issue IV, traced the economy principle through ellipsis, linking it to the psychological states of the characters in the epics. Based on numerous examples, she demonstrates that

her approach leans toward a linguo-cognitive understanding of economy. According to the researcher, ‘Due to the economy principle manifesting in human psychology, only those linguistic phenomena remain stable and effective in which minimal respiratory effort, ease of memorization, and invariability of form are combined. From this perspective, syntactic constructions with elliptical forms enjoy semantic freedom in grammatical completion’” (12, pp. 75–76).

“Ə. Abdullayev, Y. Seyidov, and A. Həsənov, in their 2002 publication Müasir Azərbaycan dili (Modern Azerbaijani Language), particularly in the section on simple sentences in the syntax chapter intended for higher education students, approached the economy principle from a linguistic-structural perspective, providing abundant examples illustrating the manifestation levels of such syntactic units” (13, pp. 205–215).

“K. Abdulla, in his 2016 textbook Azərbaycan dili sintaksisinin nəzəri problemləri (Theoretical Problems of Azerbaijani Syntax), specifically in the section The Function of Sentence Members in Azerbaijani, examined the principle of linguistic economy from a theoretical-linguistic perspective. He analyzed cases of laconic expression, compactness, and abbreviation as they manifest in the syntactic nature of sentence elements within a text, explaining that these phenomena arise from the specific communicative roles and functions of sentence members and the functional value of language means within the complete syntactic structure. He concluded that ‘the manifestation of the economy principle within a sentence primarily occurs due to the ellipsis of one or another sentence member’ (14, pp. 91–92; 72).”

“K. Abdullayev, linking ellipsis comprehensively with the suppressive phenomenon, notes that ‘its [suppressive-K.H.] salient feature is that, within a sentence, it can be easily restored at any time depending on the speaker’s intention or desire’ (14, p. 92). He precisely establishes the parallelism between ellipsis and mental representation, emphasizing that ‘ellipsis, i.e., the omission of a sentence member, does not mean that it has not occupied its proper syntactic position; it is not “forgotten.” Its presence can be realized through the sentence’s position, which is conditioned by the broader text and situational context. In this way, ellipsis is “recalled” or filled’ (14, p. 93). K. Abdullayev proposes three directions for the restoration of ellipsis in the Azerbaijani language and examines each of these directions separately in his work (15, pp. 93–98).”

The author, in their 2022 study titled “Levels of Manifestation of the Linguistic Economy Principle in Azerbaijani Prose Texts”, in the subchapter “Analysis of Economy from a Psycholinguistic Perspective”, approaches the principle of linguistic economy from pragmatic, sociological, linguocultural, mass communication, and communicative perspectives. The study demonstrates that “the principle of economy is, in general, a significant problem in linguistics. This principle is conditioned by various extralinguistic factors. It is influenced by psychological, psychophysiological, and social factors (such as the memory and cognition of language users, and the situational contexts of their interactions). The theory of economy actualizes general ideas in language and speech, defines the anthropocentric orientation of language, and contributes to the development of pragmalinguistics, mass communication theory, stylistics, and speech culture” (16, pp. 18–19).

Thus, the study of the principle of linguistic economy in the Azerbaijani language and its literary-stylistic system is presented in approximately this manner. By comparison, foreign scholarly literature provides more extensive investigations of this linguistic phenomenon. In the global linguistic landscape, the tendency toward economy in languages with different systems was first studied by Boduende Kurtene. In addition to identifying several factors essential for the emergence of this tendency, he emphasized the significant role of development from concreteness to abstraction (17, p. 56). This indicates that the author approached the principle of economy from the perspective of the strong mutual semantic connection between language and culture, thereby encompassing a linguocultural dimension.

In Russian linguistics, A. Martini was the first to extensively apply the principle of economy at the phoneme level. In his 1960 work, The Principle of Economy and Phonetic Phenomena, he analyzed economy in the language system through phenomena such as sound loss, assimilation, dissimilation, and metathesis using a historical-comparative method. This approach revealed the characteristic factors underlying these processes (18, p. 101), which, in our view, can appropriately be regarded as a linguo-phonetic perspective.

The Russian linguist Y. M. Lotman published his monograph Analysis of the Poetic Text in 1970, in which he expressed and highlighted the principle of linguistic economy in poetic language as a prominent scholarly position and leitmotif. He noted that a relatively short poem can convey information that a multivolume non-literary text cannot express (19, p. 35). In another work, Lotman explored in detail the specific spectra of the economy principle in poetic language (20, pp. 45–81). The basis of Lotman’s reflections on the principle of economy clearly lies in the linguostructural type of approach, which is characterized by the fact that the principle of economy serves as a crucial linguistic attribute for the text and its structural organization.

The Russian linguist V. A. Serebrennikov examined the principle of linguistic economy from a linguocultural perspective, giving particular attention to its psychophysiological aspects. He wrote: “At the root of the tendency toward economy lies the human organism. In language, the principle of economy manifests as a specific form of self-preservation instinct. It is a unique reaction against the overexertion of physiological tension, countering any form of discomfort that complicates memory functioning and interferes with certain brain functions involved in speech production and perception” (21, p. 22).

The Russian researcher I. F. Vardul investigated the principle of economy at the language level from a stylistic perspective, associating it primarily with suppressiveness. According to the researcher, “to ellipsize the syntactic-semantic unit (‘sintaksemi’) is to econo-

mize its content" (22, p. 63). Although the author expresses this idea concisely, it conveys to the reader that he attributed significant importance to the linguo-structural and semantic type of economy.

In English linguistics, Jespersen briefly related the different types and forms of economy to the ellipsization of certain sentence elements, noting that "expression is what the speaker gives, whereas economy is what he could give but does not" (23, p. 359).

The French linguist S. Balli examined linguistic economy from conceptual and situational perspectives and explicitly summarized these in his work General Linguistics and Issues of the French Language. Conceptual and situational economy, according to Balli, means that in his studies, he approached this linguistic phenomenon from a linguo-magnetic perspective, noting that "ellipses in words, word combinations, and sentence models economized in a text can be restored with the help of context and the syntactic whole" (24, p. 99).

Each method reflects the natural development of the language and responds to various purposes linked to its cultural and social life (Ismayil, 2024). Q. Paul emphasized that forms of linguistic economy, even when not actively used, are represented in the language-consciousness, that is, in thought within the brain, carrying both concrete and abstract meanings. He noted that "in this context, abstraction should be considered one of the primary factors for achieving an economized state" (25, p. 95).

The Russian orientalist and distinguished linguist V. V. Vinogradov, discussing the factors that determine economy in poetic contexts, emphasized the structural type of this principle, noting that "the work of a poet can only be compared to the skillful labor of a master jeweler. After all, a word is like gold" (26, p. 22).

Conclusion

From the analysis of these studies, it can be summarized that at the First Turkological Congress, Shcherba and Ziffeld briefly addressed the principle of linguistic economy primarily from a physiopsychological perspective. This marked the first embryonic conceptualization of one of the essential aspects of this linguistic phenomenon in the global linguistic context. Over the subsequent century, the principle of economy has been theoretically investigated across its various types and categories. However, despite this theoretical elaboration, the exploration of the concept of economy in poetry—particularly its unique linguo-cultural and semiotic characteristics—remains underdeveloped. The studies conducted so far have primarily focused on structural, phonological, syntactic, and pragmatic aspects, while the cultural, cognitive, and stylistic dimensions of poetic economy have not been systematically addressed. Therefore, this gap highlights the necessity of a dedicated research endeavor that examines how linguistic economy operates within literary texts, how it interacts with cultural and cognitive factors, and how it contributes to the efficiency, expressivity, and aesthetic density of poetic discourse. Such a study would not only deepen our understanding of the principle of economy in the Azerbaijani language and other Turkic languages but would also provide valuable insights into the intersection of language, cognition, and culture in literary expression.

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MOTIVATION, AUTONOMY, AND ENGAGEMENT IN CONTENT-AND-LANGUAGE INTEGRATED LEARNING

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ABSTRACT

Content-and-Language Integrated Learning (CLIL) has increasingly gained recognition as a dynamic and innovative educational approach that simultaneously promotes the acquisition of subject knowledge and the development of foreign language proficiency. Motivation is widely acknowledged as a critical factor influencing learners' willingness to invest effort and persist in challenging tasks, while autonomy allows students to take responsibility for their own learning, make strategic choices, and reflect on their progress. Engagement, encompassing behavioral, emotional, and cognitive dimensions, represents learners' active involvement and sustained attention during instruction. In CLIL contexts, these three elements are deeply interconnected: motivated learners are more likely to engage fully with content, engaged learners develop greater independence, and autonomous learners often maintain higher levels of intrinsic motivation.

This article explores these interrelationships, examining how CLIL environments, characterized by meaningful content, interactive and collaborative pedagogies, and authentic language use, can foster sustained motivation, promote learner autonomy, and enhance engagement. The paper further addresses challenges to maintaining motivation and autonomy in CLIL classrooms, such as linguistic difficulties, cognitive load, teacher preparedness, and assessment practices.

Overall, this article argues that CLIL is not only a methodology for combining content and language but also a holistic approach that cultivates motivated, self-directed, and actively engaged learners, preparing them for success in increasingly multilingual, intercultural, and knowledge-driven educational environments.

Keywords: CLIL, learner motivation, learner autonomy, engagement, bilingual education, integrated learning.

Introduction

In the context of globalized education and increasingly multilingual societies, the demand for innovative teaching approaches that combine language learning with subject knowledge has grown significantly [18]. Traditional language instruction, which often isolates linguistic competence from meaningful content, may fail to engage learners fully or to develop higher-order thinking skills. Content-and-Language Integrated Learning (CLIL) has emerged as a response to this challenge, offering a pedagogical framework in which academic subjects are taught through a foreign or additional language [9]. By integrating language and content instruction, CLIL allows learners to acquire subject-specific knowledge while simultaneously developing linguistic proficiency, creating a more authentic, functional, and motivating learning experience [9].

Unlike traditional language instruction, where language is taught as an isolated skill, CLIL integrates academic content with language learning, allowing learners to use the target language as a functional tool to access, process, and communicate disciplinary knowledge. This dual focus not only supports linguistic competence but also encourages deeper cognitive engagement and meaningful interaction with academic material [16].

Over the past two decades, research has highlighted the cognitive, academic, and socio-emotional benefits of CLIL; however, the affective dimensions of learning—particularly motivation, learner autonomy, and engagement—have become increasingly central in understanding the success of CLIL programs.

Beyond its focus on linguistic and cognitive outcomes, CLIL has increasingly been recognized for its potential to influence affective and motivational dimensions of learning. The approach is particularly relevant in diverse educational contexts, where students often face varying levels of language proficiency, cultural backgrounds, and academic readiness [20]. In these settings, understanding the factors that drive learner engagement, foster autonomy, and sustain motivation is essential to achieving successful learning outcomes [4]. Motivation, defined as the internal and external forces that initiate, direct, and sustain learning behaviors, plays a central role in CLIL because students are frequently required to process complex subject matter in a language that is not their mother tongue [19]. Likewise, learner autonomy, which involves the ability to take responsibility for one's learning, make strategic choices, and reflect on progress, is crucial in CLIL classrooms that emphasize inquiry-based, collaborative, and student-centered pedagogies. Engagement, encompassing behavioral, emotional, and cognitive dimensions, ensures that learners actively participate in meaningful tasks and maintain sustained attention throughout the learning process [19].

CLIL environments provide unique opportunities to nurture these dimensions through several mechanisms. First, the integration of authentic and contextually meaningful content encourages intrinsic motivation, as learners perceive their language use as purposeful rather than artificial [7]. Second, interactive and collaborative activities, including projects, discussions, and problem-solving tasks, foster both autonomy and

engagement, allowing learners to take initiative and actively co-construct knowledge [Wolff]. Third, the challenges inherent in processing academic material in a foreign language can strengthen learners' resilience, self-regulation, and metacognitive skills, all of which are closely linked to motivation and autonomy [5]. Importantly, these factors are interdependent; motivated learners are more likely to engage meaningfully, engaged learners often develop greater autonomy, and autonomous learners frequently sustain higher intrinsic motivation [10].

This article explores the interrelated roles of motivation, learner autonomy, and engagement within CLIL contexts, emphasizing their significance in creating effective, inclusive, and learner-centered classrooms [13]. Drawing on theoretical frameworks from constructivist and sociocultural perspectives, as well as empirical studies from multilingual educational settings, the paper examines how CLIL pedagogies can foster these dimensions and discusses the practical challenges and implications for classroom implementation [1]. By focusing on affective and cognitive factors alongside linguistic and academic outcomes, this study provides a holistic understanding of how CLIL can cultivate motivated, self-directed, and actively engaged learners prepared to navigate increasingly multilingual and intercultural educational environments.

CLIL is broadly defined as an educational approach in which a foreign or additional language is used as the medium of instruction for non-language subjects. Unlike traditional language teaching, CLIL positions language as a tool rather than an end goal. Learners acquire linguistic competence through meaningful exposure to academic content, resulting in more authentic and purposeful language use [17].

The theoretical underpinnings of CLIL draw from constructivist learning theory, sociocultural theory, and communicative language teaching. Constructivist perspectives emphasize active knowledge construction, while sociocultural theory highlights the importance of interaction and scaffolding in learning. These frameworks align with CLIL principles, as learners engage in problem-solving, collaboration, and contextualized communication.

A widely cited framework within CLIL research is the 4C model, which consists of Content, Communication, Cognition, and Culture. This model underscores the holistic nature of CLIL, integrating cognitive development, language use, and intercultural awareness. Motivation, autonomy, and engagement are embedded within this framework, as learners are encouraged to think critically, communicate meaningfully, and take responsibility for their learning.

Learner Motivation in CLIL Contexts

Motivation is commonly defined as the internal and external forces that initiate, direct, and sustain learning behavior. In educational psychology, motivation is often categorized into intrinsic and extrinsic types. Intrinsic motivation refers to learning driven by interest or enjoyment, while extrinsic motivation involves external rewards or obligations [17].

In language learning, motivation is considered a key predictor of success. However, traditional foreign language classrooms may struggle to maintain learners' motivation due to limited authenticity and relevance. CLIL addresses this issue by embedding language use within meaningful academic contexts. Motivation is a critical factor in any learning environment, but it becomes particularly central in CLIL settings, where students are expected to learn subject content through a foreign or additional language [7]. CLIL enhances motivation through multiple mechanisms, drawing on both intrinsic and extrinsic motivational factors, and creating learning experiences that are meaningful, challenging, and authentic.

One of the primary ways CLIL enhances motivation is by providing authentic and meaningful content. Instead of learning language in isolation, students encounter it as a tool to access knowledge in subjects like science, history, or mathematics. This contextualized use of language increases the perceived relevance of both the language and the subject matter, fostering intrinsic motivation [3]. For example, when students conduct experiments in biology or solve real-world mathematical problems in English, they recognize the practical utility of their learning. This sense of purpose encourages learners to invest effort voluntarily, which is a key aspect of intrinsic motivation. Research indicates that learners in CLIL classrooms report higher interest and enjoyment compared to peers in traditional language classrooms, largely due to the meaningful integration of content and language.

CLIL also promotes motivation by enhancing learners' sense of achievement and self-efficacy [14]. While initially challenging, mastering subject content through a second language provides students with tangible evidence of their progress and competence. Overcoming linguistic and cognitive challenges fosters a sense of accomplishment, which strengthens confidence and self-belief. The theory of self-determination suggests that competence is one of the three basic psychological needs for motivation [17]. CLIL satisfies this need by allowing learners to experience mastery not only in the subject matter but also in using language as a functional tool, reinforcing both motivation and engagement.

CLIL classrooms often include a variety of interactive and cognitively challenging tasks, such as problem-solving activities, debates, collaborative projects, and presentations. This diversity of tasks stimulates curiosity and curiosity-driven motivation. The cognitive challenge inherent in processing content through a second language encourages learners to focus, persist, and develop resilience. According to flow theory, optimal learning occurs when tasks are challenging yet achievable; CLIL naturally creates such conditions, allowing students to experience flow and sustained intrinsic motivation [19].

CLIL enhances motivation by incorporating collaborative learning and peer interaction. Working in pairs or groups, learners negotiate meaning, share knowledge, and provide feedback, which reinforces a sense of community and relatedness—another key component of self-determination theory. This social dimension of learning promotes motivation, as learners

are encouraged to contribute actively and see the impact of their participation on collective outcomes. For example, a group project in history conducted in a foreign language requires learners to coordinate, communicate, and problem-solve together, enhancing both motivation and engagement.

Another motivational mechanism in CLIL is its connection to learners' future academic and career aspirations. Proficiency in a foreign language combined with subject knowledge is increasingly valued in higher education and professional contexts. When students recognize the real-world benefits of their learning, motivation is reinforced through extrinsic factors, such as potential opportunities for international study, employment, or academic recognition [20]. CLIL thus bridges classroom learning with meaningful future-oriented goals, providing both intrinsic and extrinsic incentives for engagement.

Finally, CLIL teachers play a central role in sustaining motivation. Through scaffolding, encouragement, and adaptive support, teachers help learners navigate linguistic and cognitive challenges without overwhelming them. Providing timely feedback, acknowledging effort, and setting achievable goals contribute to learners' motivation. When students feel supported yet challenged, they are more likely to persist, engage, and take ownership of their learning [9].

CLIL enhances motivation through a combination of authentic content, achievement experiences, cognitive challenge, collaborative tasks, future relevance, and teacher support. These factors work synergistically to foster intrinsic motivation while supporting extrinsic goals, ensuring that learners remain engaged, confident, and persistent in their learning journey. By situating language learning within meaningful, goal-oriented tasks, CLIL transforms the classroom into a motivating and dynamic environment that promotes both academic and linguistic success.

Learner Autonomy in CLIL

Learner autonomy refers to the ability and willingness of learners to take responsibility for their own learning. Autonomous learners are capable of setting goals, monitoring progress, selecting strategies, and reflecting on outcomes [6]. Autonomy is not an innate trait but a skill that develops through supportive learning environments.

In multilingual education, autonomy is particularly important, as learners must navigate linguistic and cognitive challenges independently. CLIL classrooms provide a fertile ground for fostering autonomy due to their emphasis on inquiry-based learning and problem-solving.

CLIL pedagogy often incorporates project-based learning, collaborative tasks, and inquiry-driven activities. These practices require learners to make decisions, conduct research, and manage learning processes actively [Wolff]. As a result, students gradually develop independence and self-regulation skills.

Additionally, CLIL encourages metacognitive awareness. Learners reflect not only on subject content but also on language use and learning strategies. This dual focus enhances self-awareness and supports lifelong learning competencies.

Teachers in CLIL contexts play a facilitative role, guiding learners through scaffolding rather than direct instruction. This shift in teacher–learner dynamics empowers students and promotes autonomy [10].

Learner Engagement in CLIL Classrooms

Learner engagement is a multidimensional construct encompassing behavioral, emotional, and cognitive aspects. Behavioral engagement refers to participation and effort, emotional engagement involves interest and enjoyment, and cognitive engagement relates to deep processing and critical thinking [8]. High levels of engagement are associated with improved academic outcomes, persistence, and positive attitudes toward learning. CLIL classrooms, by design, aim to activate all three dimensions of engagement.

Engagement through Integrated Learning

CLIL enhances engagement by combining content-rich instruction with interactive language use. Lessons often involve discussions, problem-solving tasks, experiments, and group projects, which stimulate active participation.

The use of authentic materials and real-life topics further increases engagement [2]. Learners are more likely to invest effort when content is relevant and intellectually stimulating. Moreover, the cognitive challenge of processing information in another language encourages deeper engagement and sustained attention [5].

Collaborative learning is another key factor. Through peer interaction, learners negotiate meaning, share perspectives, and co-construct knowledge, leading to enhanced engagement and social learning.

Interrelationship Between Motivation, Autonomy and Engagement

Motivation, autonomy, and engagement are closely interconnected and mutually reinforcing. Motivated learners are more likely to engage actively, while engaged learners tend to develop greater autonomy. Similarly, autonomous learners often demonstrate higher motivation due to increased ownership of learning.

CLIL environments support this dynamic interplay by offering meaningful challenges, choice, and opportunities for reflection [17]. When learners feel competent, supported, and involved, they are more likely to take initiative and sustain engagement.

Understanding this interrelationship is essential for effective CLIL implementation. Teachers who design lessons that address these dimensions simultaneously can create more inclusive and motivating learning experiences [17].

Motivation, learner autonomy, and engagement are three interrelated constructs that play a central role in successful learning within CLIL environments [11]. Although each can be studied independently, research and educational theory suggest that these dimensions are dynamically connected, mutually reinforcing, and collectively influential in shaping learners' academic, linguistic, and socio-emotional outcomes [10]. Understanding their interrelationship is critical for designing CLIL classrooms that maximize student potential and promote holistic development.

Motivation and Engagement

Motivation is often considered the driving force behind engagement. Learners who are intrinsically motivated are more likely to invest effort, participate actively, and persist in cognitively demanding tasks [1]. In CLIL settings, motivation is stimulated by authentic content, meaningful communication, and the practical application of language [7]. When learners perceive tasks as relevant and attainable, they are more likely to engage behaviorally, emotionally, and cognitively. Behavioral engagement manifests as active participation in classroom activities, completion of assignments, and consistent effort in both language and content learning [20]. Emotional engagement is expressed through interest, enthusiasm, and positive attitudes toward the subject matter, while cognitive engagement reflects deep processing, critical thinking, and problem-solving [21]. The dynamic between motivation and engagement is cyclical: motivated learners engage more fully, and sustained engagement further reinforces motivation by providing evidence of competence and achievement [8].

Autonomy and Motivation

Learner autonomy and motivation are closely linked. Autonomous learners, who can set goals, monitor their progress, and select appropriate learning strategies, often experience higher intrinsic motivation [6]. CLIL promotes autonomy by requiring students to navigate content in a foreign language, make strategic decisions during problem-solving tasks, and take responsibility for understanding both subject matter and linguistic structures. Autonomy fosters a sense of ownership over learning, which strengthens learners' intrinsic motivation [18]. Conversely, motivated learners are more likely to exercise autonomy effectively because they are willing to engage with tasks, take initiative, and persist in challenging situations. This bidirectional relationship underscores the importance of designing CLIL experiences that simultaneously encourage self-directed learning and maintain learners' motivation through relevant and achievable challenges [19].

Autonomy and Engagement

Learner autonomy also has a significant impact on engagement. Autonomous learners are more likely to engage in tasks meaningfully, employ strategies to overcome difficulties, and sustain attention in cognitively demanding activities [8]. In CLIL classrooms, autonomy-supportive practices—such as project-based learning, collaborative inquiry, and choice in assignments—enable learners to participate actively, make decisions about their learning, and reflect on outcomes. These opportunities not only enhance behavioral engagement but also promote cognitive and emotional involvement. For example, when learners are given autonomy to research a topic of interest in a second language and present their findings collaboratively, they demonstrate both deep cognitive processing and emotional investment in the task [9].

Motivation, Autonomy, and Engagement in a Synergistic Cycle

The interrelationship among motivation, autonomy, and engagement can be conceptualized as a synergistic cycle in CLIL contexts. Motivation drives engagement, engagement reinforces autonomy, and autonomy strengthens motivation. Each construct amplifies the others, resulting in a cumulative effect on learning outcomes [8]. For instance, motivated learners are more likely to take initiative, engage deeply with tasks, and apply autonomous strategies [1]. As learners successfully navigate challenges independently, their engagement intensifies, creating a reinforcing loop that sustains intrinsic motivation and fosters long-term academic and linguistic growth.

Understanding this interrelationship has important implications for CLIL pedagogy. Teachers can enhance learning outcomes by creating environments that simultaneously address all three dimensions [7]. Strategies may include designing tasks that are both challenging and meaningful, offering opportunities for learner choice and self-direction, promoting collaborative and interactive activities, and providing scaffolding and feedback to support persistence. By attending to the interconnected nature of motivation, autonomy, and engagement, educators can cultivate classrooms in which learners are not only linguistically and academically competent but also confident, self-directed, and actively invested in their learning [22].

Motivation, autonomy, and engagement are mutually reinforcing elements within CLIL classrooms [10]. Their dynamic interplay creates a synergistic cycle in which motivated learners engage more deeply, autonomous learners maintain sustained motivation, and engaged learners develop greater independence. Effective CLIL instruction capitalizes on this interrelationship by fostering meaningful, interactive, and learner-centered experiences that integrate content mastery with language development, promoting holistic learning outcomes [5].

Challenges in Promoting Motivation and Autonomy in CLIL

Despite its benefits, CLIL is not without challenges. Linguistic difficulty may initially reduce learners' confidence and motivation, particularly for students with lower language proficiency. Without appropriate scaffolding, cognitive overload can occur.

Teacher preparedness is another critical issue. Effective CLIL instruction requires expertise in both subject content and language pedagogy. Insufficient training may limit teachers' ability to support learner autonomy and engagement effectively [19]. Assessment practices also pose challenges. Traditional testing methods may not adequately capture learners' progress in CLIL contexts, potentially affecting motivation [15]. Alternative assessment strategies, such as formative feedback and self-assessment, are essential for sustaining learner engagement.

To maximize motivation, autonomy, and engagement in CLIL, educators should adopt learner-centered strategies. These include differentiated instruction, collaborative learning, and formative assessment [5]. Clear learning objectives and transparent expectations can reduce anxiety and support motivation.

Teachers should also encourage reflection and self-assessment to promote autonomy. Providing choices in tasks and topics allows learners to align learning with personal interests, further enhancing engagement [1].

Professional development programs are crucial for equipping teachers with the skills needed to design effective CLIL lessons. Ongoing support and collaboration among educators can contribute to sustainable and high-quality CLIL implementation.

Conclusion

Content-and-Language Integrated Learning represents a powerful educational approach that extends beyond linguistic and academic achievement. By fostering motivation, autonomy, and engagement, CLIL supports holistic learner development and prepares students for the demands of multilingual and globalized societies [12].

This article has highlighted the ways in which CLIL enhances intrinsic motivation through meaningful content, promotes learner autonomy via active and reflective practices, and sustains engagement through integrated and interactive instruction [23]. While challenges remain, thoughtful pedagogical design and teacher preparation can ensure that CLIL environments remain inclusive, motivating, and effective [5]

Future research should continue to explore learner experiences across diverse contexts and educational levels, contributing to a deeper understanding of how CLIL can best support motivated, autonomous, and engaged learners.

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ПІДГОТОВКА МАЙБУТНІХ ВИКЛАДАЧІВ ІНОЗЕМНИХ МОВ НА ОСНОВІ ІНСТРУМЕНТІВ ШТУЧНОГО ІНТЕЛЕКТУ

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TRAINING FUTURE FOREIGN LANGUAGES TEACHERS BASED ON ARTIFICIAL INTELLIGENCE TOOLS

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АНОТАЦІЯ

У статті проведено аналіз інструментів штучного інтелекту, які застосовуються у навчанні майбутніх викладачів іноземних мов, оцінка їх ефективності, доступності та зручності використання.

ABSTRACT

The article analyzes artificial intelligence tools used in training future foreign languages teachers, assessing their effectiveness, accessibility, and ease of use.

Ключові слова: штучний інтелект (ШІ), інструменти штучного інтелекту, нейронні мережі, ChatGPT**,** вивчення/навчання іноземних мов, методики викладання іноземних мов.

Keywords: artificial intelligence (AI), artificial intelligence tools, neural networks, ChatGPT, foreign language learning/teaching, foreign languages teaching methods.

Метою даного дослідження є вивчення можливостей використання штучного інтелекту (ШІ) у процесі навчання/вивчення іноземних мов, виявлення основних проблем, пов'язаних із впровадженням даних технологій в освітній процес та аналіз інструментів ШІ, що застосовуються для навчання/вивчення іноземних мов, оцінки їх ефективності та зручності використання як для викладачів, так і студентів.

Основою для аналізу є публікації в наукових журналах у галузі освітніх технологій та викладання іноземних мов. У цьому дослідженні було проведено огляд літератури з вивчення наукових джерел для виявлення основних напрямів застосування ШІ у навчанні/вивченні іноземних мов, оцінки поточних досягнень і виявлення перспективних тенденцій.

У сфері вивчення іноземних мов з допомогою штучного інтелекту проводиться безліч досліджень. У своєму дослідженні Н.С. Зулкарнайн і М.М.Юнус виявили, що педагоги сприймають інтеграцію технології ШІ позитивно через її динамічні характеристики та ефективність, незважаючи на різні проблеми, які призводять до недоліків, пов'язаних з її використанням [8]. У дослідженні Р.Ругайя проведено систематичний огляд потенціалу ШІ у покращенні лінгвістичних здібностей, зроблено висновок, що ШІ пропонує адаптивний навчальний досвід, інтерактивні та занурювальні навчальні середовища, миттєвий зворотний зв'язок та доступ до широкого спектру ресурсів, допомагаючи студентам розширювати свої знання про мову, покращувати навички говоріння [6]. С.Алмелхес, розмірковуючи про роль ШІ в навчанні другої мови, пише, що алгоритми ШІ можуть значно поліпшити вивчення і володіння майже будь-яким діалектом [1].

Виклад основного матеріалу дослідження. Ключовим елементом застосування технологій штучного інтелекту в навчанні виступає персоналізація та можливість побудови індивідуальних методів навчання з урахуванням інтересів, особистісних потреб та індивідуальних особливостей студентів. Персоналізоване навчання – це така система навчання та розвитку особистості, в якій студент виступає основним суб'єктом навчального процесу, взаємодіючи з викладачем та інструментами ШІ відповідно до індивідуальних здібностей, здійснює вибір методів, засобів навчання, визначає темп оволодіння навчальним матеріалом та бере на себе відповідальність за результат навчання.

Індивідуальна практика студентів з конкретними інструментами ШІ здійснюється позааудиторно у зручний для користувачів час та місці. Крім того, багато інструментів ШІ здатні адаптувати складність навчального матеріалу та інтенсивність навчання відповідно до когнітивних можливостей студентів та їх рівнем оволодіння дисципліною.

Інструменти ШІ можуть стати незамінним помічником сучасного викладача іноземних мов для вирішення *методичних* проблем. З їх допомогою можна здійснювати тематичне планування, складати плани тематичних занять, створювати тренувальні вправи і творчі завдання, спрямовані на розвиток різних видів мовленнєвої діяльності, а також завдання на переклад. Серед інструментів ШІ, які допомагають викладачеві вирішувати методичні проблеми, можна виділити ChatGPT, YandexGPT, GigaChat і нейромережу для викладачів Twee, яка сприяє створенню методичних матеріалів. На сучасному етапі нейромережа ChatGPT 4.0 є найбільш популярним іструментом ШІ, здатним значно полегшити традиційні функції викладача з розробки навчальних матеріалів для занять.

Слід зазначити, що коректність матеріалів, розроблених нейромережею, залежить від промпту, сформульованим користувачем. У деяких випадках, щоб отримати бажану інформацію або навчальні матеріали, викладачеві необхідно буде зробити декілька запитів. Працюючи на основі великих мовних моделей ChatGPT і GigaChat іноді можуть надавати недостовірні дані або некоректні приклади. При цьому, багато користувачів відзначають, що нейромережі Twee, GigaChat і YandexGPT чудово справляються зі складанням планів занять на задану тему, які не потрібно видозмінювати або доробляти. У разі необхідності ШІ дає рекомендації викладачеві з доопрацювання плану. Залежно від промпту план заняття може містити завдання з розвитку чотирьох іншомовних умінь і навчання аспектам іноземних мов (граматиці, фонетиці, фонетиці, лексиці).

Чат-боти з генеративним ШІ можуть бути також корисні під час створення текстів для читання чи перекладу. Викладачеві не потрібно займатися довгим пошуком тексту, а просто ввести в нейромережу необхідний промпт, після чого отримати бажаний текст з необхідною структурою, лексичними засобами, граматичними конструкціями. Відзначимо, що на момент дослідження GigaChat не має можливості введення і виведення інформації за допомогою голосу, тому використовувати його при розвитку таких видів мовної діяльності, як говоріння і аудіювання, не уявляється можливим. Це також варто враховувати при складанні тренувальних вправ та завдань на аудіювання.

В даний час на ринку програмного забезпечення існує багато інструментів ШІ, спрямованих на надання користувачам *автоматизованої якісної чи кількісної оцінки* виконаного завдання у вигляді тесту або контрольної роботи, у тому числі творчого характеру. ШІ здатний миттєво надати користувачеві якісну та кількісну оцінку, на відміну від викладача, у якого перевірка тестів і контрольних робіт може зайняти кілька днів.

Вивчення лінгводидактичного потенціалу багатьох інструментів ШІ виступало предметом дослідження багатьох вчених. Зокрема, Дж. М.Демсбі [2], Дж.Парк [5], А.Пердана і М. Фаріда [4] вивчали здатність платформи Grammarly надати оцінку написаних есе за такими критеріями, як структура есе, лексика, чіткість викладу аргументів. Х.Йанг, Ч.Гао, Х.Шен [7] вивчали здібності платформи Pigai в оцінці лексики, граматики, пунктуації та орфографії.

Аналіз даних досліджень показує, що на сучасному етапі всі перераховані інструменти ШІ здатні якісно оцінити правильність використання студентами лексичного і граматичного матеріалу, дотримання заявленої структури роботи. Разом з тим, предметом обговорення виступає здатність ШІ оцінити зміст творчої роботи. З усіх наведених інструментів ШІ тільки ChatGPT 4.0 здатний якісно оцінити зміст роботи. На сучасному етапі ChatGPT 4.0 зрівнявся з викладачем щодо оцінки письмових творчих робіт за такими критеріями: зміст роботи, підтвердження ідей та аргументів, організація та структура есе. Більше того, за такими критеріями, як мова есе та його оригінальність, інструмент ШІ перевершив викладача. Мовна модель ChatGPT 4.0, що функціонує на основі автентичних текстів, може правильно визначити мовні неточності студентів краще викладача, що не є носієм мови.

Викладачі і студенти можуть використовувати нейромережі ChatGPT, GigaChat і YandexGPT для пошуку необхідної інформації. У підготовці майбутніх викладачів іноземних мов *інформаційний-довідковий матеріал* може включати як матеріали теоретичного і практичного характеру. У рамках викладання теоретичних дисциплін інформаційно-довідковий матеріал може включати матеріали основ теоретичної граматики, лексикології, стилістики, фонетики, мовознавства.

Студенти можуть використовувати інформаційні-довідкові функції ШІ у позааудиторний час, якщо у них є потреба у більш ретельному вивченні теоретичного матеріалу або відпрацюванням мовних навичок. Інформаційно-довідкову функцію ШІ доцільно використовувати в рамках теоретичних, практичних, мовних дисциплін, під час педагогічної практики і в курсових і кваліфікаційних роботах.

Поряд із очевидними перевагами, технології штучного інтелекту можуть також викликати певні ризики та загрози викладачам та студентам. Такі ризики можуть виникнути у сфері збереження конфіденційності персональних даних, дотримання принципів авторської етики при взаємодії з штучним інтелектом тощо.

Висновки. Штучний інтелект в освіті продовжує розвиватися, відкриваючи нові можливості для персоналізації навчання, підвищення його доступності та ефективності. Цей процес також ставить перед дослідниками та викладачами нові питання, пов'язані з етикою, безпекою даних та рівністю доступу до освітніх ресурсів. Дослідження підтверджують, що впровадження ШІ в освіту сприяє персоналізації навчання та оптимізації навчальних процесів, покращує розуміння матеріалу студентами та покращує їх мотивацію.

Перспективи подальшої роботи полягають у розробці методик навчання аспектам іноземних мов, видам мовленнєвої діяльності, а також профільним дисциплінам на основі конкретних інструментів ШІ. У своїй сукупності дані методики дозволять створити цілісну систему лінгвометодичної підготовки майбутніх викладачів іноземних мов на основі інструментів ШІ.

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TECHNICAL SCIENCES

SYNTHESIS OF AN ASYNCHRONOUS ELECTRIC MOTOR USING THE MULTIPARAMETRIC DESIGN METHOD

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ABSTRACT

The subject of this study is a methodology for obtaining (synthesizing) the main attributes of an electromechanical energy converter, using an asynchronous electric motor as an example. This article examines an approach to organizing the calculation and modeling of the main attributes of an asynchronous electric motor. It demonstrates that considering multi-physical parameters, such as electrodynamic, mechanical, and thermal properties, improves the design quality both functionally and intellectually. The mathematical apparatus of the study is based on the parametric design of power machines. The synthesis resulted in design information on the main operating parameters of an asynchronous electric motor, which is sufficient for selecting a motor model from the manufacturer's catalog for subsequent use in design work.

Keywords: power machine, electrodynamic, mechanical and thermal processes, electric motor, synthesis of design.

Statement of the problem

The process of designing electromechanical energy converters is a complex and multifaceted task, which, on the one hand, is limited by the technical and methodological capabilities of the existing design tools, and on the other hand, by the modern requirements of the market for electromechanical equipment, which include the requirements of manufacturability, safety, environmental friendliness and reasonable economy of the future unit. Currently, known design methods are based on the sequential organization of calculation stages, followed by the process of modeling individual phenomena and effects of the functioning of the electric machine and modeling, at the final stage, the future design of the electromechanical energy converter. This approach affects both the timing of design work and the quality of individual results obtained as a result of design [1]. At the current stage of development of electrical engineering, the most actively used methodology of design work using computer-aided design systems (Computer-aided design, i.e. CAD). The mechanism of implementation of these systems is carried out by various methods, methods and models. Calculations in CAD are mostly performed by the following methods [2-5]:

- finite element method;
- finite difference method;
- finite volume method;
- boundary element method, etc.

CAD systems allow modeling of the solid-state structure of an electric machine taking into account the influence of electromagnetic, mechanical, hydraulic and thermal loads on it, which as a result makes it possible to obtain the value of the real design of the electromechanical converter for the subsequent manufacturing process and its assembly at an industrial site.

The quality requirements of electrical power equipment determine the following strategy for the development of the design of electromechanical energy converters [6]:

– use of case insulation and winding insulation of reduced thickness, including to achieve an increase in the coefficient of groove filling with copper and more rational use of the total volume of the machine;

– use of modern materials for electrical insulation, which have an increased class of heating resistance (class F and H);

– use of improved grades of electrical steel with increased magnetic permeability and lower loss rates;

– increase in the cooling efficiency of the electric machine by improving the gas path for cooling the core, winding, rotor and housing as a whole and improving the design and operating mode of fans and gas coolers (air coolers);

– rejection of hydrogen cooling medium (in powerful generators) and use of air agent for cooling the electric machine;

– reduction of the mass and dimensions of the structural elements of the electric machine (housing, shields, bearings, etc.);

– development and further use of typical solutions to improve manufacturability in production, to reduce specific costs at the production stage;

– improvement of the mathematical apparatus of CAD systems to increase the accuracy of the results obtained and reduce the timing of design and engineering work.

Research goals and objectives

The aim of the work is to synthesize the main attributes of an asynchronous electric motor using the multiparametric design method of power machines. The obtained data should contain design information sufficient to select a brand of power machine for further use in design work.

Material and essence of the research

1. Mathematical modeling

An induction motor (AM) is usually described in two complementary forms: through a steady-state-matched equivalent circuit (for steady-state modes and frequency characteristics) and through a coordinate transformation in *dq* for dynamics, control, and transients. The generalized equation of the phase frequency resistance of the stator $Z_s(\omega)$ and the rotor $Z_r(\omega)$ of an induction motor, in complex form, has the following form:

$$\begin{cases} Z_s(\omega) = R_s + j \cdot \omega \cdot L_{\sigma s}, \\ Z_r(\omega) = \dfrac{R_r}{s} + j \cdot \omega \cdot L_{\sigma r}; \end{cases} \quad (1)$$

where, R_s and R_r are the active resistance of the stator and rotor, respectively, Ohm; $L_{\sigma r}$ and $L_{\sigma s}$ are the inductive dissipation index of the rotor and stator, respectively, Hn; j – an imaginary unit for the complex representation of phase shifts; ω – the angular frequency of the electrical network, Hz; s – the rotor slip, a.u.

Then the electromagnetic moment of the AM in the coordinates ω and s is equal to:

$$M_e(\omega, s) = \frac{3}{\omega_s} \cdot \frac{R_r}{s \cdot \left(\dfrac{R_r}{s}\right)^2 + \left(\omega \cdot L_{\sigma r} + \dfrac{\omega \cdot L_m \cdot Z_s}{Z_s + j \cdot \omega \cdot L_m}\right)^2} \cdot \Phi_e^2; \quad (2)$$

where, ω_s – angular frequency of the stator electric field, Hz; L_m – magnetizing inductance of the AM, Hn; Φ_e – effective flux linkage, in a simplified model the moment is classically written through the "moment" characteristic of the rotor with a magnetic component in parallel, a.u.

In addition to the electromagnetic moment of the AM, we present a system of flux linkage equations in *dq*-coordinates to take into account the dynamic component of the multiparametric model:

$$\begin{cases} u_{sd} = R_s \cdot i_{sd} + \dfrac{d\psi_{sd}}{dt} - \omega_s \cdot \psi_{sq}, \\ u_{sq} = R_s \cdot i_{sq} + \dfrac{d\psi_{sq}}{dt} + \omega_s \cdot \psi_{sd}, \\ 0 = R_r \cdot i_{rd} + \dfrac{d\psi_{sr}}{dt} - \omega_{sl} \cdot \psi_{rq}, \\ 0 = R_r \cdot i_{rq} + \dfrac{d\psi_{rq}}{dt} + \omega_{sl} \cdot \psi_{rd}; \end{cases} \quad (3)$$

where, u_{sd} and u_{sq} – the voltage of the stator of the AM in the coordinates *dq*, V; i_{sd} and i_{sq} – the current of the stator of the AM in the coordinates *dq*, A; ψ_{sd} and ψ_{sq} – the index of the flux linkage of the stator of the AM in the coordinates *dq*, a.u.; ψ_{rd} and ψ_{rq} – the index of the flux linkage of the rotor of the AM in the coordinates *dq*, a.u. $\omega_{sl} = \omega_s - \omega_r$ – the slip frequency, which is equal to the difference between the frequency of the electromagnetic field of the stator and the frequency of mechanical rotation of the rotor, Hz.

In this case, the relationship between currents and flux linkage of the AC can be formulated as follows [7]:

$$\begin{cases} i_{sd} = \dfrac{\psi_{sd} - \dfrac{L_m}{L_{\sigma r}} \cdot \psi_{rd}}{L_{\sigma s} + \dfrac{L_m^2}{L_{\sigma r}}}, \quad i_{sq} = \dfrac{\psi_{sq} - \dfrac{L_m}{L_{\sigma r}} \cdot \psi_{rq}}{L_{\sigma s} + \dfrac{L_m^2}{L_{\sigma r}}}, \\ i_{rd} = \dfrac{\psi_{rd} - \dfrac{L_m}{L_{\sigma s}} \cdot \psi_{sd}}{L_{\sigma r} + \dfrac{L_m^2}{L_{\sigma s}}}, \quad i_{sq} = \dfrac{\psi_{rq} - \dfrac{L_m}{L_{\sigma s}} \cdot \psi_{rq}}{L_{\sigma r} + \dfrac{L_m^2}{L_{\sigma s}}}; \end{cases} \quad (4)$$

When designing an AM with the ability to use multiparameterization properties, the variables become geometry, materials, connection schemes, types of cooling, restrictions on electric current density and electric load. Therefore, the expression M_e must be represented with a dependence on the vector of parameters p and include both electromechanical and additional elements (multiphysical). The composition of the vector may vary depending on the purpose and conditions of the real project, but in the basic value it must contain the following information blocks, according to the expression below:

$$\mathrm{p} = f\left(R_c, N_s, N_r, d_s, l_s, \mu(B,\omega), \sigma_{cu}(T,\omega), \sigma_{al}(T,\omega) d_{sp}, d_{rp}\ b_r, b_s, h_r, h_s, g, L_m, ...\right) \quad (5)$$

a) electrical parameters:

R_c – equivalent electrical energy losses of the stator core, W;

d_s and l_s – diameter and length of the stator core, m;

N_s, and N_r – number of turns / rods of the stator and rotor winding, pcs.

b) parameters of the properties of the structural material:

$\mu(B, \omega)$ – complex magnetic permeability of the core material, which depends on the frequency of the electric current, H/m;

$\sigma_{Cu}(T, \omega)$ and $\sigma_{Al}(T, \omega)$ – electrical conductivity of copper and aluminum of the stator and rotor windings, Cm.

d_{sp} and d_{rp} – diameter of the wire from which the stator and rotor windings are made, m.

c) geometric parameters:

b_r and b_s – width of the rotor and stator slot, respectively, m;

h_r and h_s – depth of the rotor and stator slot, respectively, m;

g – width of the air gap between the inner diameter of the stator and the outer diameter of the rotor, m.

d) electromagnetic indicators:

L_m – inductance of the magnetizing component of the AM, a.u.

Table 1 shows a comparison of information blocks (variables) with the characteristics of their influence on the AM.

Table 1

Correlation of information variables with the characteristics of their influence on an asynchronous electric motor

Parameter	Impact on asynchronous electric motor
R_c	Determines the efficiency index, the degree of core heating, the amount of frequency losses
d_s and l_s	Limits the electromagnetic flux and the shape of the magnetic field, influences the magnitude of the electromechanical moment, determines the losses of electrical energy, and greatly affects the mass index of the AM.
N_s, and N_r	Mainly determines the EMF, forms the flux, affects the magnetizing inductance of the core
$\mu(B, \omega)$	Determines the inductance of the active zone of the AM and affects electrical energy losses
$\sigma_{Cu}(T, \omega)$ $\sigma_{Al}(T, \omega)$	Determine the active losses of the windings and the degree of heating of the active parts of the AM
d_{sp} and d_{rp}	Affects resistance, thermal regime and parasitic capacitances in the active part of the AM
b_r and b_s	Determines the current density of the windings, determines the dissipation losses, determines the resistance and inductance of the winding cores
h_r and h_s	
g	It has great importance for the entire electromagnetic state of the AM, determines the magnetizing current and moment of inertia
L_m	Determines the ability of the stator core to store magnetic energy

Taking into account the parameter vector p, we rewrite the system of flux linkage equations in AM:

$$\begin{cases} u_{sd} = R_s \cdot i_{sd} + \dfrac{d\psi_{sd}}{dt} - (\omega_{sl} + \mathrm{p} \cdot \omega_m) \cdot \psi_{sq}, \\ u_{sq} = R_s \cdot i_{sq} + \dfrac{d\psi_{sq}}{dt} + (\omega_{sl} + \mathrm{p} \cdot \omega_m) \cdot \psi_{sd}, \\ 0 = R_r \cdot i_{rd} + \dfrac{d\psi_{sr}}{dt} - (\omega_s - \mathrm{p} \cdot \omega_m) \cdot \psi_{rq}, \\ 0 = R_r \cdot i_{rq} + \dfrac{d\psi_{rq}}{dt} + (\omega_s - \mathrm{p} \cdot \omega_m) \cdot \psi_{rd}; \end{cases} \quad (6)$$

where, ω_m – mechanical speed of the AM, Hz.

Having transformed the system of equations (1) taking into account (5) and (6), the multiparametric model of the complex phase resistance of the AM will be obtained:

$$\begin{cases} Z_s(\omega) = R_s + j \cdot \omega \cdot L_{\sigma s}, \\ Z_r(\omega, s) = \dfrac{R_r}{s} + j \cdot \omega \cdot L_{\sigma r}, \\ Z_m(\omega) = j \cdot \omega \cdot L_m \| R_c; \end{cases} \quad (7)$$

As a result of constructing the above mathematical apparatus, the multiparametric model of the electromagnetic moment of the AM in the coordinates ω and s, with parametric sensitivity, has the form shown in Fig. 1.

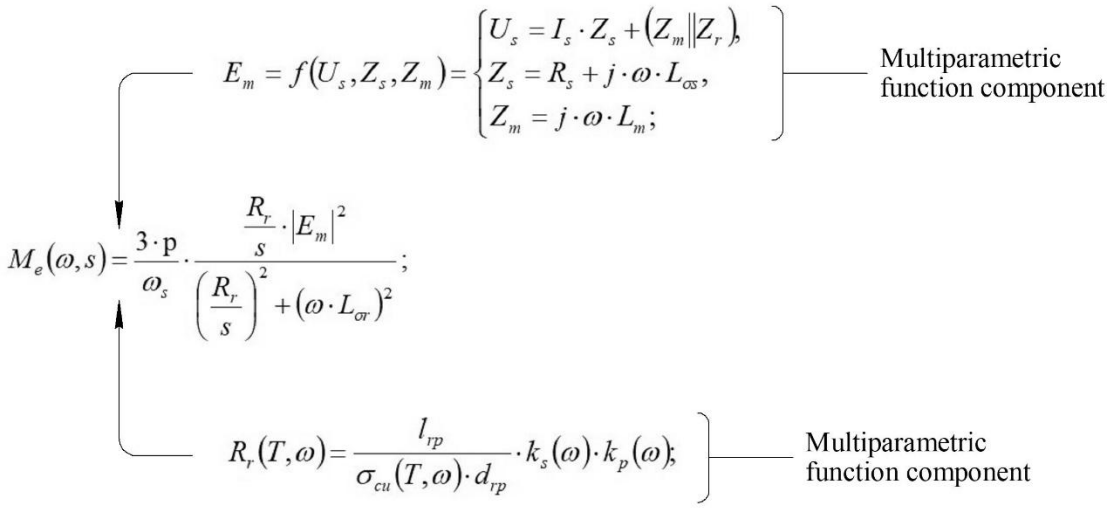
$E_m = f(U_s, Z_s, Z_m) = \begin{cases} U_s = I_s \cdot Z_s + (Z_m \| Z_r), \\ Z_s = R_s + j \cdot \omega \cdot L_{\sigma s}, \\ Z_m = j \cdot \omega \cdot L_m; \end{cases}$
Multiparametric function component
$M_e(\omega, s) = \frac{3 \cdot p}{\omega_s} \cdot \frac{\frac{R_r}{s} \cdot |E_m|^2}{\left(\frac{R_r}{s}\right)^2 + (\omega \cdot L_{\sigma r})^2};$
$R_r(T, \omega) = \frac{l_{rp}}{\sigma_{cu}(T, \omega) \cdot d_{rp}} \cdot k_s(\omega) \cdot k_p(\omega);$
Multiparametric function component

Fig. 1. Multiparametric mathematical model of the electromagnetic torque of an asynchronous electric motor

Fig. 1 shows:

E_m – EMF of the magnetic component of the electromagnetic system of the AM; l_{rp} – length of the rotor winding conductor (rod or turn), m; d_{rp} – diameter (or cross-sectional area) of the conductor, mm^2; $k_s(\omega)$ – coefficient of increase in resistance due to the effect of current displacement, a.u.; $k_p(\omega)$ – coefficient of increase in resistance due to the effect of proximity (mutual influence of neighboring conductors) of conductors, a.u.

Having examined Figure 1 in detail, the following conclusions can be drawn regarding the obtained multiparametric mathematical model of an asynchronous electric motor, when using it in design work [8]:

- parameters located in the volume of the vector **p** are included in the *dq*-equation using the resistances and inductance indices of the electromagnetic system of the AM, which are determined by the geometry, materials and frequency of the electromagnetic field;
- a stationary electromagnetic circuit of the AM with a slip allows you to model and obtain the operating characteristics of the EM (such as current, torque, efficiency, etc.);
- the mechanical and electromagnetic parts of the multiparametric model are based on the multiphysical nature of the processes, which allows for the correction and optimization of efficiency and loss indicators, starting characteristics, and specific current indicators of the AM.

2. Implementation of the design method

In this section, we will perform multiparametric design of an asynchronous electric motor, the purpose of which is to determine the main geometric and structural parameters (for example, the number of slots, stator diameter and stator core length) and electromechanical and electromagnetic parameters (performance). To develop such an AM, we will use the provisions specified in [9].

Development object: asynchronous electric motor.

Initial data: power 18.5 kW, nominal speed 1500 rpm, mains voltage 220/380/660 V, frequency 50 Hz.

The design results are presented in Table 2.

Table 2

Results of designing an asynchronous electric motor

Параметр	Модель (описова частина):	Value type, and result
Productivity	$\begin{cases} P_{em} = \frac{P_2}{\eta \cdot \cos\varphi} \cdot \frac{E_{f1}}{U_n}, \\ P_{em} = m_1 \cdot U_n \cdot I_n \cdot \frac{\cos\varphi}{\cos\varphi_g}; \end{cases}$	Numerical: 18.5 kW
Rotation frequency	$n_2 = \frac{60 \cdot f_n}{p} \cdot (1 - s);$	Numerical: 1470 rpm (nominal)
Stator outer diameter	$D_1 = \sqrt{\frac{6.1 \cdot P_{em} \cdot 10^4}{\alpha_i \cdot k_\Phi \cdot k_0 \cdot A \cdot B_\delta \cdot n_2 \cdot l_1}};$	Numerical: 330 mm.
Stator core length	$l_1 = \frac{E_{f1} \cdot I_n \cdot p \cdot m_1}{k_\Phi \cdot k_0 \cdot f_n \cdot \pi^2 \cdot \alpha_i \cdot A \cdot B_\delta \cdot D^2};$	Numerical: 230 mm.
Number of stator and rotor slots	$z_1 = 6 \cdot p \cdot q_1; \quad z_2 = 4 \cdot p \cdot q_2;$	Integer: 48 stator 28 rotor

Rotor type	It is determined structurally: phase or squirrel-cage rotor type	Category: phase
Type of climatic design	Classification according to GOST 15150-69: U, UHL, TV, TS, T, O, M, TM, OM, V.	List: type selected – U
Structural design	Classification according to DSTU GOST 2479-79: IM101X, IM202X, IM301X, IM401X …	List: selected – IM101X
Cooling type	Classification according to DSTU GOST 20459-87: IC01, IC06, IC411, IC416, IC410, IC37 …	List: selected – IC411

Conclusion

From the results of Table 2 we have that the AM provides the required power at four-pole rotations – 1470 rpm, the dimensions of the stator core are in the standardized range of this EM class (330 × 230 mm), the number of rotor and stator slots also belongs to the recommended range of values: for the stator – 48 … 72 slots, for the rotor – 28 … 36 slots [10], in order to improve the starting torque and smooth speed control of the AM, the phase rotor type was selected, the climatic design type is moderate (*U*), the most unified design type is on the legs, with one or two bearing shields, cooling is implemented using a built-in fan, in a closed housing, as well as with heat dissipation from the outside of the housing [11]. As a result of multiparametric design, the following possible AM design options were determined, which are given in Table 3. In our case, only option number 1 is suitable, because only it has a phase rotor with a minimum EM mass index and a relatively low rated current, the other three options only provide information about the adequacy and reliability of the results obtained by matching the received design information.

Table 3.

Options for selecting an asynchronous electric motor based on design results

№	Brand	Power, kW	Voltage, V	Rotation speed rpm	Rotor type	Efficiency %	cos φ	Hold, A	Weight kg
1	AIR-160M4	18,5	380	1500	Phasic	89,0	0,86	22,5	95
2	AIM160M4	18,5	380	1500	Phasic	90,0	0,86	36,3	162
3	AM160M4	18,5	380	1500	Short-circuited	90,0	0,86	36,3	162
4	5A160M4	18,5	380	1500	Phasic	90,0	0,86	34,7	150

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АВТОМАТИЗАЦИЯ УПРАВЛЕНИЯ ВИРТУАЛЬНЫМИ МАШИНАМИ И ОБЛАЧНЫМИ РЕСУРСАМИ С ИСПОЛЬЗОВАНИЕМ AZURE FUNCTIONS

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AUTOMATE THE MANAGEMENT OF VIRTUAL MACHINES AND CLOUD RESOURCES USING AZURE FUNCTIONS

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АННОТАЦИЯ

В данной работе предложен практический подход к автоматизации управления виртуальными машинами в Microsoft Azure с использованием бессерверной платформы Azure Functions и службы безопасного хранения секретов Azure Key Vault. Разработанное решение реализует типовые операции запуска и остановки виртуальных машин в Azure по HTTP-запросам, при этом доступ к ресурсам осуществляется через библиотеку Azure Resource Manager SDK для .NET. Для защиты аутентификационных данных используется хранилище секретов и механизм управляемой идентификации, что позволяет исключить хранение учётных данных в коде и конфигурационных файлах.

Предложенный подход реализован на основе модели изолированного процесса выполнения (isolated worker model) для C# Azure Functions, что обеспечивает независимость версии .NET от среды выполнения и облегчает дальнейшую эволюцию решения.

ABSTRACT

This paper presents a practical approach to automating the management of virtual machines in Microsoft Azure using the serverless platform Azure Functions and the Azure Key Vault service for secure secret storage. The developed solution exposes HTTP-triggered functions that start and stop virtual machines in Azure, using the Azure Resource Manager SDK for .NET for resource access. Authentication data is stored in Azure Key Vault and accessed through managed identities, which eliminates credentials from the application code and configuration files.

The proposed approach is implemented using the isolated worker model for C# Azure Functions, providing decoupling between the .NET runtime version and the Azure Functions host.

Ключевые слова: виртуальные машины, Azure Functions, Azure Key Vault, Azure Resource Manager, автоматизация, облачная инфраструктура, управляемая идентичность, информационная безопасность.

Keywords: virtual machines, Azure Functions, Azure Key Vault, Azure Resource Manager, automation, cloud infrastructure, managed identity, information security.

Во многих инфраструктурах Microsoft Azure развернуты виртуальные машины, которые используются нерегулярно: персональные серверы для отдельных сотрудников, временные тестовые стенды, учебные и лабораторные среды. Их постоянная работа экономически невыгодна, но и задать фиксированное расписание включения и выключения обычно невозможно: график использования зависит от людей, проектов и меняется от недели к неделе. В таких условиях классический подход с ручным управлением через портал Azure быстро перестаёт быть удобным и масштабируемым, а попытки жестко формализовать расписание часто приводят к тому, что части ресурсов либо простаивают включёнными, либо оказываются недоступными в нужный момент.

Дополнительным ограничением является уровень доступа конечных пользователей. Не всегда допустимо предоставлять им вход в портал Azure или Azure-подписку даже с урезанными правами: на одном и том же портале могут быть видны конфиденциальные ресурсы, информация о других проектах или средах, финансовые параметры подписки. Во многих организациях доступ к порталу получают только администраторы и ограниченный круг ответственных лиц, тогда как разработчикам, тестировщикам или отдельным сотрудникам требуется лишь возможность управлять “своей” виртуальной машиной - запустить её перед началом работы и остановить по завершении задач.

Среди встроенных средств автоматизации в экосистеме Azure можно выделить Azure

Automation, ориентированный на выполнение сценариев по расписанию и управляемых Runbook-процессов. Такой инструмент эффективен там, где режим эксплуатации ресурсов можно заранее описать в виде стабильного графика, например: включение рабочей среды утром в будни и отключение вечером. Однако для серверов с плавающим или непредсказуемым режимом использования жёсткое расписание неудобно и часто не отражает реальных потребностей. Возникает потребность в более гибком подходе, который позволял бы запускать и останавливать виртуальные машины как по запросу пользователя, так и при необходимости по расписанию, но без выдачи широкого доступа к порталу и без передачи чувствительных параметров подключения.

В этих условиях бессерверная платформа Azure Functions оказывается удобным инструментом для построения лёгкого сервисного слоя поверх существующей инфраструктуры виртуальных машин. Функции с HTTP-триггером могут вызываться из внутренних порталов, чат-ботов, скриптов или систем управления заявками, предоставляя пользователю простой интерфейс “включить/выключить сервер” без прямого доступа к подписке Azure. При этом сами функции, работая в модели изолированного процесса выполнения на платформе .NET, используют библиотеку Azure Resource Manager SDK для обращения к виртуальным машинам и другой инфраструктуре, а сервис Azure Key Vault отвечает за безопасное хранение данных аутентификации и параметров подключения. Такое сочетание технологий позволяет одновременно решить три ключевые задачи: снизить затраты за счёт отключения неиспользуемых ВМ, предоставить гибкое и удобное управление без доступа к порталу и обеспечить соблюдение требований конфиденциальности и информационной безопасности.

Для реализации сервиса управления виртуальными машинами была выбрана максимально простая и в то же время безопасная схема размещения ресурсов. Внутри подписки двух тенантов Azure создаются отдельные группы ресурсов. В первом размещаются все компоненты, отвечающие за логику управления: приложение Azure Functions и хранилище секретов Azure Key Vault. Служебные ресурсы, такие как учетная запись хранения, Application Insights или инфраструктура, автоматически создаваемая при развертывании функционального приложения, в рамках данной работы подробно не рассматриваются, так как не требуют сложной настройки и не влияют на общую архитектуру решения [1].

Во втором находится сама виртуальная машина, которой необходимо управлять. Остальные объекты инфраструктуры, неизбежно сопровождающие ВМ в Azure (виртуальная сеть, сетевые интерфейсы, публичный IP-адрес и т.п.), в статье также опускаются, поскольку их конфигурация не влияет на принцип работы сервиса и не требует изменений по сравнению с типовым сценариями развертывания виртуальных машин [1]. На схеме ресурсов виртуальная машина представлена как единственный элемент правой группы ресурсов, тогда как слева показаны Azure Functions и Key Vault, объединённые в отдельный логический контур.

Связующим звеном между функцией и виртуальной машиной выступает объект Service Principal, через который приложение получает доступ к целевой группе ресурсов (рис. 1). Вместо предоставления самому приложению широких ролей уровня подписки используется более жёсткая модель: для Service Principal создаётся и назначается отдельная роль в рамках нужной ресурсной группы. Для корректной работы сервиса эта роль должна, с одной стороны, иметь возможность просматривать все ресурсы внутри группы, чтобы библиотека Azure Resource Manager могла получить сведения о виртуальной машине и её состоянии, а с другой - обладать только минимально необходимыми правами на выполнение операций запуска и остановки конкретных ВМ [4].

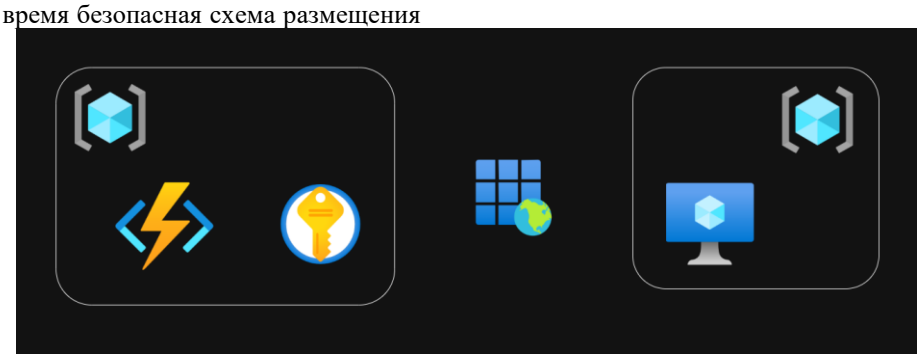

Рисунок 1. Архитектура ресурсов в Azure

Во встроенных ролях Azure существуют варианты, которые технически позволяют решать такую задачу, например роли уровня Virtual Machine Contributor, однако они включают заметно больший набор действий, чем требуется в данном сценарии [4]. С точки зрения информационной безопасности это нежелательно: приложение, отвечающее лишь за старт и стоп, не должно иметь права на создание, удаление или изменение параметров виртуальной машины. Поэтому на основе механизма Azure RBAC была разработана собственная кастомная роль (VM Power Operator, рис.2), в дефиниции которой явно перечислены только операции чтения ресурсов в группе и вызов действий start/stop для виртуальных машин [5]. Такой подход позволяет соблюсти принцип минимально необходимых привилегий и упростить аудит прав доступа.

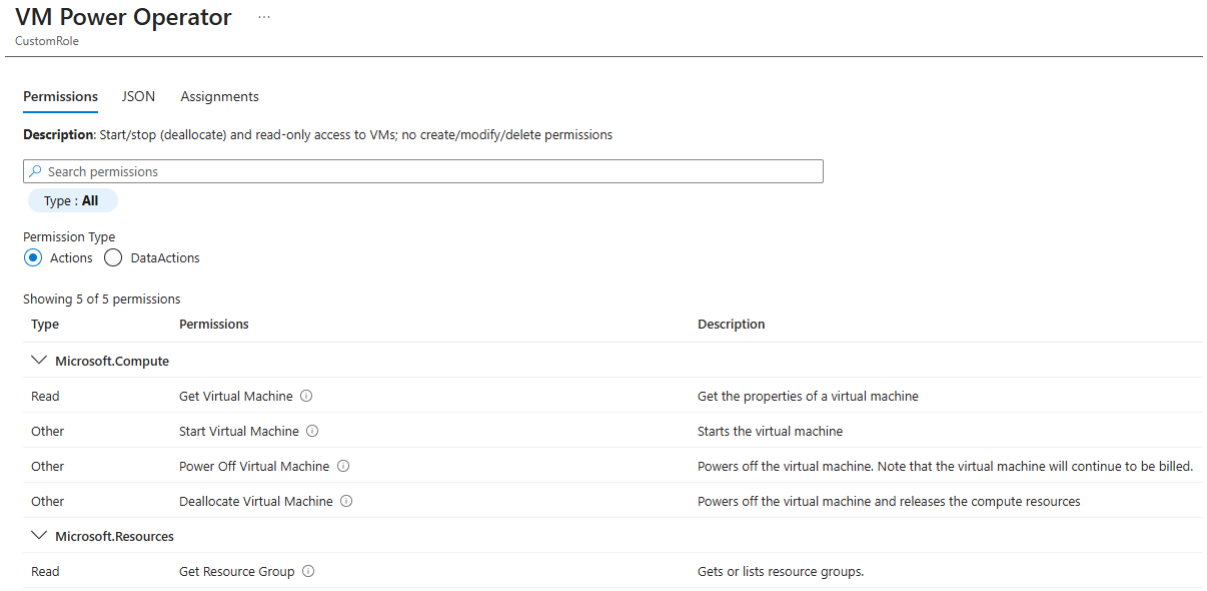

Рисунок 2. Права кастомной роли

Отдельного обоснования требует выбор модели размещения самого функционального приложения. В Azure Functions доступно несколько вариантов хостинга, среди которых классический Consumption-план, Premium-план и Flex Consumption-план [1, 6]. Поскольку в рассматриваемом сценарии обращения к функции происходят относительно редко и носят вспомогательный характер, постоянное выделение под неё отдельного App Service плана с фиксированной стоимостью представляется избыточным. Consumption-план, напротив, опирается на модель оплаты “pay-as-you-go” и тарифицирует только фактические запросы и потреблённые ресурсы, при этом предоставляя бесплатный лимит вызовов в месяц [7]. Для подобного сервиса, который активируется лишь по необходимости, такая модель оказывается наиболее экономически целесообразной.

Дополнительным аргументом в пользу выбора Consumption-плана стала поддержка привычного для .NET-разработчика сценария деплоя через Visual Studio с использованием публикации в виде ZIP-пакета. Zip-deploy является популярным механизмом развертывания приложений Azure Functions в планах Consumption, Premium и Dedicated [2], что позволяет минимизировать сложность инфраструктуры развертывания и упростить обновление кода. Альтернативные варианты хостинга, такие как Premium или Flex Consumption, могут быть оправданы в случаях, когда требуются более жёсткие требования по производительности, длительности выполнения или приватным сетям [6], однако для демонстрируемого сервиса управления виртуальными машинами типичный Consumption-план даёт оптимальное сочетание гибкости, стоимости и простоты сопровождения.

Для того чтобы функция могла управлять виртуальной машиной, используется двухуровневая схема аутентификации через сервисные учётные записи (service principal). На первом уровне сама Azure Function обладает собственной управляемой идентичностью, которая в Azure фактически представлена как отдельный service principal. Именно этой идентичности предоставляется доступ к хранилищу секретов Azure Key Vault, что позволяет функции безопасно считывать параметры подключения, не храня их в открытом виде ни в коде, ни в файлах конфигурации [3].

Во втором уровне задействуется отдельный service principal, от имени которого выполняются операции над виртуальными машинами в целевой группе ресурсов. Его идентификатор клиента, идентификатор арендатора, пароль (client secret) и идентификатор подписки сохраняются в Key Vault в виде секретов. На рисунке 3 показан пример набора таких секретов: remote-tenant-id, remote-client-id, remote-client-secret и remote-subscription-id. При вызове функции эти значения извлекаются из хранилища, после чего на их основе создаётся объект учётных данных ClientSecretCredential и клиент Azure Resource Manager SDK для .NET, обеспечивающий доступ к ресурсам подписки [3, 4].

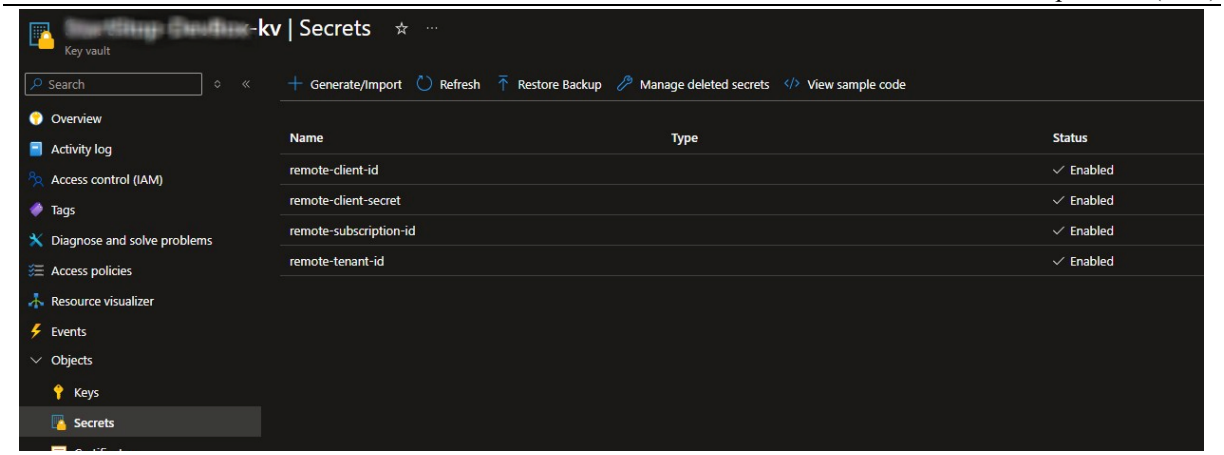

Рисунок 3. Key Vault и секреты для доступа к service principal

Теоретически можно было бы выдать самой функции прямые права на управление виртуальной машиной в рамках одного тенанта и обойтись без отдельного service principal для инфраструктуры. Однако в более общем случае виртуальные машины, которыми нужно управлять, могут находиться в разных подписках и даже в разных арендаторах Azure. Роли RBAC назначаются внутри конкретного каталога и подписки [5], поэтому хранение параметров нескольких service principal в Key Vault делает решение более гибким: одна и та же функция в своём тенанте может обращаться к разным клиентским средам, используя разные пары “tenant–client” и соответствующие им роли. Такой подход особенно актуален, когда команда разработчиков работает по модели аутсорсинга, а виртуальные машины развернуты в арендаторах заказчиков.

В результате функция получает доступ к Key Vault через свою управляемую идентичность и только к секретам, которые ей необходимы. А уже эти секреты содержат параметры удалённого service principal, у которого в целевой группе ресурсов есть минимально необходимые права: просмотр ресурсов и выполнение операций запуска и остановки виртуальных машин [4, 5]. Такая раздельная модель аутентификации позволяет одновременно выдержать принцип наименьших привилегий и подготовить решение к возможным сценариям межтенантного управления.

Реализация сервиса управления виртуальными машинами основана на двух HTTP-функциях: StartVMHttpTrigger и StopVMHttpTrigger (рис. 4). Обе функции оформлены в виде классов с единообразной структурой: через конструктор им передаётся экземпляр логгера ILogger, а основной код располагается в методе Run, помеченном атрибутом Function. Атрибут HttpTrigger задаёт, что функция вызывается по HTTP-запросу метода GET с уровнем авторизации Function, то есть для доступа требуется ключ функции [2].

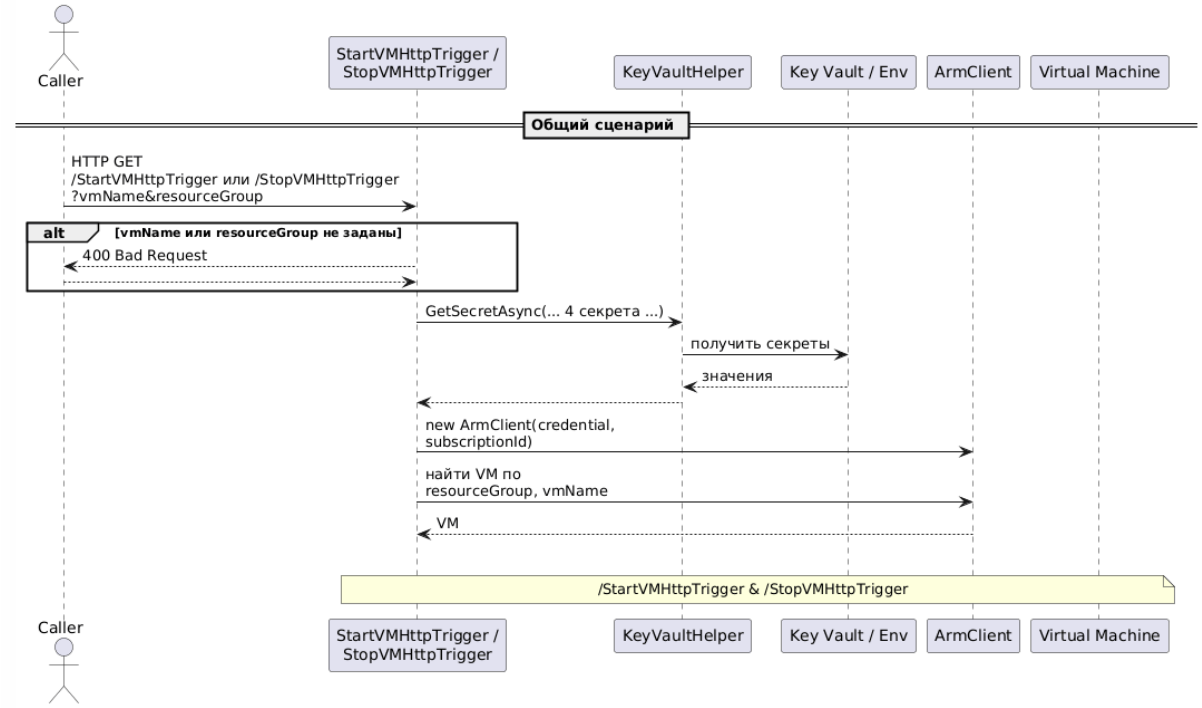

Рисунок 4. UML диаграмма взаимодействия триггеров с виртуальной машиной

Функция начала работы виртуальной машины StartVMHttpTrigger при каждом запросе извлекает из строки запроса два обязательных параметра: имя виртуальной машины (vmName) и имя ресурсной

группы (resourceGroup). При отсутствии любого из них сразу возвращается ответ с кодом 400 и сообщением о необходимости передать оба параметра. Такой предварительный контроль входных данных позволяет не выполнять лишние обращения к инфраструктуре и упрощает диагностику ошибок на стороне вызывающего клиента.

После проверки параметров создаётся экземпляр вспомогательного класса KeyVaultHelper, отвечающего за доступ к секретам. С его помощью из Azure Key Vault последовательно считываются четыре значения: идентификатор арендатора, идентификатор клиента, секрет клиента и идентификатор подписки удалённого service principal. Эти значения используются для построения объекта ClientSecretCredential из библиотеки Azure.Identity, который инкапсулирует аутентификацию по приложению. На основе этих учётных данных создаётся клиент Azure Resource Manager ArmClient, предоставляющий программный доступ к подписке и группам ресурсов [4].

Далее функция получает ссылку на подписку и целевую ресурсную группу, после чего извлекает объект виртуальной машины с указанным именем. На этом этапе в журнал записывается информация о том, какая именно машина и в какой группе будет запускаться, что облегчает аудит операций. Основное действие выполняется вызовом метода PowerOnAsync с параметром ожидания завершения операции. После успешного запуска формируется HTTP-ответ с кодом 200 и JSON-телом, содержащим сообщение, имя виртуальной машины, ресурсную группу и статус Started. В случае любой ошибки исключение перехватывается, записывается в лог с привязкой к имени виртуальной машины, а клиенту возвращается код 500 и текст с описанием причины сбоя.

Функция остановки виртуальной машины StopVMHttpTrigger реализована аналогичным образом и использует тот же набор библиотек. Разница заключается в вызываемой операции над виртуальной машиной: вместо запуска используется метод DeallocateAsync, который деаллокацирует ресурсы вычисления и позволяет снизить стоимость содержания сервера, в том числе за счёт освобождения выделенных ресурсов [4]. Возвращаемый ответ также оформляется в виде JSON-структуры, где статус изменяется, например, на deallocated, что даёт вызывающей стороне однозначное представление о результатах работы.

Отдельного внимания заслуживает вспомогательный класс KeyVaultHelper. В его конструкторе из переменных среды считывается параметр KeyVaultUri. Если он задан, создаётся клиент SecretClient с использованием DefaultAzureCredential. Такой подход рекомендует сама документация Microsoft, поскольку DefaultAzureCredential автоматически выбирает корректный способ аутентификации в зависимости от среды: локально это может быть учётная запись разработчика, а в Azure - управляемая идентичность функции [3]. При отсутствии KeyVaultUri класс переключается в режим работы с переменными окружения, что позволяет запускать и отлаживать функцию, не имея развёрнутого Key Vault. Метод GetSecretAsync в явном виде обрабатывает возможные ошибки, выбрасывая осмысленные исключения, если секрет не найден ни в хранилище, ни в переменных среды.

Таким образом, код функций не содержит жёстко прописанных строк подключения или секретов и опирается на современную модель аутентификации через Azure SDK для .NET. Логика приложений остаётся максимально компактной: каждая функция последовательно выполняет валидацию параметров, получение секретов, инициализацию клиента управления ресурсами, поиск виртуальной машины и вызов требуемой операции, при этом все детали доступа к секретам спрятаны за отдельным вспомогательным компонентом.

Выводы: В работе рассмотрен практический подход к автоматизации управления виртуальными машинами в Microsoft Azure на основе бессерверной платформы Azure Functions. Предложенное решение реализует отдельный сервисный слой, вынесенный в собственную группу ресурсов и использующий Azure Key Vault для безопасного хранения параметров аутентификации. За счёт двухуровневой схемы работы с сервисными учётными записями приложение получает минимально необходимые права на выполнение операций запуска и остановки виртуальных машин, не раскрывая конечным пользователям структуру подписки и не предоставляя им прямой доступ к порталу Azure. Это позволяет снизить затраты за счёт своевременного отключения неиспользуемых серверов и упростить управление инфраструктурой в сценариях с плавающим графиком использования ресурсов.

Реализация сервиса на базе HTTP-функций в модели изолированного процесса выполнения для .NET показала, что даже относительно небольшой объём кода, опирающийся на Azure Resource Manager SDK и стандартные механизмы аутентификации, может обеспечить гибкое и расширяемое управление виртуальными машинами. Выбор варианта хостинга по модели Consumption делает решение экономически выгодным для систем с редкими обращениями, а использование кастомной роли в Azure RBAC позволяет выдержать принцип наименьших привилегий. В дальнейшем тот же подход может быть распространён на другие типы ресурсов и сценарии, включая более сложные варианты автоматизации, где требуется управлять несколькими средами и интегрироваться с корпоративными порталами, системами заявок и конвейерами CI/CD.

Репозиторий с кодом Azure Function:
https://github.com/qwesszaq/StartStopVMFunction

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